4

EPISTEMIC ACTION AND LANGUAGE: A CROSS-LINGUISTIC STUDY

Warren King

A minor dissertation submitted in partial fulfilment of the requirements for the award of the degree of
MASTER OF ARTS (PSYCHOLOGICAL RESEARCH)
in the Faculty of Humanities
UNIVERSITY OF CAPE TOWN
2008

Supervisor: Susan Malcolm-Smith
Co-Supervisor: David Nunez, DPhil

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

This work has not been previously submitted in whole, or in part, for the award of any degree. It is my own work. Each significant contribution to, and quotation in, this dissertation from the work, or works, of other people has been attributed, and has been cited and referenced.

Signature: Signed by candidate Date: 26/05/2008

Abstract

Epistemic actions are physical actions which increase the speed, accuracy, and/or robustness of internal computation by allowing cognitive work to be off-loaded to the environment, thus simplifying internal computation. Previous studies on epistemic action are limited in that they demonstrate that epistemic actions may only improve task performance within tasks which are inherently spatial in nature. In this regard, a cross-linguistic replication of an experiment by Maglio *et al.* (1999) which required participants to produce as many words as possible within five minutes from a string of seven random letters was performed in order to investigate epistemic actions in a verbal task domain. Experiment 1 required one group to perform the task in English, the other in Afrikaans. It was discovered that epistemic actions aid word production in English, but that this interacts with the frequency of the words contained within the letter string used as a stimulus. The same pattern of results was obtained for Afrikaans, indicating that the experiment can be replicated cross-linguistically, and the results further indicated that cross-language interference in the task may occur. Experiment 2 was a cross-linguistic examination of the interaction between the productiveness of the letter strings used as stimuli and epistemic action, and the results indicated that the epistemic action effect was limited in this experiment, and that the letter string stimuli exerted far more of an influence on the number of words produced. Overall, the results indicate that the range of applicability of the epistemic action effect may be limited, in that although it does occur in the present experiments, it does so only in the correct context.

Acknowledgements

The financial support provided by the National Research Foundation (NRF) was invaluable in assisting with the running of the studies and the presentation of this dissertation. I would also like to acknowledge the financial support provided by the Harry Crossley Foundation, as well as the K. W. Johnstone bequest.

Thank you to my supervisor, David Nunez, whose support, opinions, and insight throughout the duration of this project were invaluable. Thank you also to the ACSENT Lab and its founders and members in the Department of Psychology at the University of Cape Town.

This dissertation is dedicated to Kate-Victoria Kempen.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Overview

This chapter presents an introduction to the theoretical construct of epistemic action, and the broader framework of distributed cognition of which it is a part. The chapter discusses the research on cognition in the computer game of Tetris on the basis of which the concept of epistemic action was primarily developed, before turning to research on epistemic action in another task domain, that of Scrabble (which is a registered trademark of Hasbro, Inc.). Finally, an overview of the present research is described.

1.2 Distributed Cognition

Epistemic actions are physical actions whose primary function is to improve cognition by simplifying computation (Kirsh & Maglio, 1994). An everyday example of such actions would be laying out the pieces of something that requires assembly in roughly the order and spatial relationship they will have in the final product (Wilson, 2002). The epistemic action hypothesis forms part of the broader theoretical field of distributed cognition. Primarily developed by Hutchins himself around this time as a new paradigm for conceptualising cognition, the field takes as its focus an explication of *cognitive systems* rather than simply internal cognitive processes alone (Rogers, 2006). Such systems are defined as the interactions between people, artefacts, and both internal and external representations (Rogers, 2006), such that the material vehicles of cognition can be spread across the biological organism and certain aspects of the physical environment itself (Clark, 2005a). Such a system typically includes multiple people interacting with each other, and a range of artefacts to perform an activity (Rogers, 2006). For example, the navigation of a ship into a harbour is a complex activity which involves the complex co-ordination of several members of the navigation team, together with the involvement and co-ordination of several artefacts such as the nautical slide rule (Rogers, 2006).

The distribution of cognitive processes may take place in three different kinds of ways (cf. Hutchins, 2000, p. 1):

- Distribution through time in such a way that the products of earlier events can transform the nature of later events.
- Distribution across members of a social group.
- Distribution in the sense that the operation of the cognitive system involves co-ordination between internal and external (material or environmental) structure.

In other words, distributed cognition involves an examination of temporally, socially, and environmentally distributed cognitive processes.

Following Hutchins (2000), the investigation of the temporal distribution of cognition can be said to be an examination of the way in which the environments of human thinking are created, developed, sustained, and changed. For example, the external environment - which may contain notations, media, and devices, such as computers, which can all augment and complement internal human cognitive processes – is actively structured by us (Clark, 1999), and this structure can alter over time. The environment can also be used as a long-term archive such as in the use of reference books, computer files, and so forth (Wilson, 2002), and in this way cognition can also be temporally distributed in that the cognitive products, such as research findings, of earlier generations can be stored in such archives and accessed by future generations.

The social distribution of cognition refers to the way in which cognition can be distributed amongst members of a social group, and is based on the assumption that cognitive systems consisting of more than one individual have properties that are different and irreducible to the cognitive properties of the individuals involved in the system (Rogers, 2006). Examples of this include Hutchins (1995, cited in Rogers, 2006) analysis of the navigation of a ship, which requires the complex co-ordination of people and artefacts (Rogers, 2006) in such a way that the cognitive task of navigation is shared and distributed amongst members of the navigational team, as well as the analysis by Hutchins and Klausen (1996) of the collaborative work and cognitive practices required for an airline cockpit to function efficiently and correctly.

The notion of the 'extended mind' put forward by Clark and Chalmers (1998) can be taken as an example of why cognition can be considered to be environmentally distributed. They state (p. 8):

> If, as we confront some task, a part of the world functions as a process which, were it to go on in the head, we would have no hesitation in accepting as part of the cognitive process, then that part of the world is (for that time) part of the cognitive process.

An example of this comes from Hutchins and Klausen (1996), which is the fact that since civil transport aircraft provide duplicate flight instruments for the two pilots, failures that might otherwise be difficult to detect can be discovered by means of cross-checking instruments. In other words, the cognitive task of detecting failures is aided by the cockpit, and the cockpit can thus be seen as being part of the cognitive system.

Although three distinct ways in which cognition can be distributed are thus distinguishable, they are not necessarily mutually exclusive, and although they can be studied individually from one another, any one particular analysis of the way in which cognition is distributed can include examining more than one type of distribution, and the analyses of Hutchins (1995, cited in Rogers, 2006), and Hutchins and Klausen (1996), for example, in fact do.

1.3 Structural Coupling, Embodiment, and Situated Cognition

Viewing the environment as part of the cognitive system allows an examination of the way in which individual agents engage with the environment to manage cognition. In this view, cognition is not seen as occurring solely inside individual agents through, for example, the manipulation of symbols or patterns of activation across arrays of processing units; rather, cognition is viewed as involving an interaction, co-ordination, and transaction between the individual agent and their environment (Clark, 1997; Hutchins, 2000).

Following this is the assumption that agents act locally and are closely, or 'structurally,' coupled to their local environment (Kirsh, 2006). Kirsh (2006, p. 250) defines close coupling in the following way:

> Let us say that two entities are closely coupled if they reciprocally interact: changes in one cause changes in the other, and the process goes back and forth in such a way that we cannot explain the state trajectory of the one without looking at the state trajectory of the other.

The agent is seen as being linked with an external entity in a two-way interaction, where all of the components in the system play an active causal role and jointly govern behaviour (Clark & Chalmers, 1998). Kirsh (2006) uses the example of a person writing on a piece of paper. He notes that the changes that a person effects to the paper cause reciprocal changes in the person which allows the person to represent and explore ideas using the persistent state of the paper that would otherwise be impossible. For example, a person may draw Venn diagrams on a piece of paper in order to determine logical relations among categories (Wilson, 2002). The changes that the person effects to the piece of paper in this case would then partially cause changes in the person, in that new logical relations could possibly be determined that otherwise may not be.

If agents are structurally coupled to their environment, the cognitive system that results from this coupling can be viewed as *embodied*. Quick and Dautenhahn (1999, cited in Ziemke, 2001) provide a definition of embodiment:

> A system X is embodied in an environment E if perturbatory channels exist between the two. That means, X is embodied in E if for every time *t* at which both X and E exist, some subset of E's possible states with respect to X have the capacity to perturb X's state, and some subsets of X's possible states with respect to E have the capacity to perturb E's state.

Ziemke (2001) notes that this definition is not very restrictive, as it does not make a distinction between cognitive and non-cognitive systems. A more restrictive notion of embodied cognition is that of 'physical embodiment,' the view that systems should be connected to their environment through a physical body, as well as sensors and motors apparatus. An even more restrictive notion is that organism-like cognition should be limited to organism-like bodies, a notion which Ziemke (2001) terms 'organismoid embodiment.' He sees the most restrictive notion of embodiment as being 'organismic embodiment,' which holds that cognition is not only limited to bodies of organism like form, but in fact only to organisms possessing a living body.

Cognition is therefore seen as being what living systems do in interaction with their environment (Ziemke, 2001), in other words, it is an interaction with those things that the cognitive activity is about (Wilson, 2002). In this sense cognition is also situated, taking place in the context of task-relevant inputs and outputs; that is, perceptual information continues to come in while a cognitive process is being carried out, and motor activity – action – is executed that affects the environment in task-relevant ways (Wilson, 2002).

Wilson (2002) notes, however, that the organisation of a cognitive system that is distributed across various situations, that is, the functional relations among its elements, would change every time a person begins interacting with a different set of objects, and therefore that systems like this would arise and disband rapidly. According to Wilson (2002), the distributed view of cognition thus trades the permanent nature of the system in order to buy a system that is more or less closed.

Adams and Aizawa (2001) have also attacked the distributed cognition view by asserting that although we may often use external artefacts in the aid of cognition, when tools and artefacts are used this does not necessarily constitute a case of these tools and artefacts being part of cognition themselves. Adams and Aizawa (2001) give as an example of the above argument the multiplication together of two numbers in two different instances, one in which the computation is performed internally, and one in which the computation is performed on a piece of paper. They argue that in the latter case, only the internal portions of the computational process are cognitive, whereas in the former case all the computational processes involved will be cognitive as they are all internal. In addition, Adams and Aizawa also note that theorists such as Clark and Chalmers (1998) commit instances of what they term the 'coupling-constitution fallacy,' which is according to them the mistaken belief that if some object or process is coupled to the cognitive agent, then this object or process is taken to be part of the cognitive system, whereas this is not necessarily the case. In other words, the causal coupling of X (the external environment) to Y (internal cognitive processes) does not necessarily mean that X is a part of Y (Menary, 2006).

Menary (2006) notes, however, that another case is possible, which is that if X is reciprocally coupled to Y, these together constitute a new process, say Z, and that "[t]he aim is not to show that artefacts get to be part of cognition just because they are causally coupled to a pre-existing cognitive agent, but to explain why X and Y are so co-ordinated that they together function as Z, which causes further behaviour" (p. 334). Menary further notes that although the manipulation of the external vehicles of cognition and the processing of internal vehicles may be different, both processes are complementary, and the processing of any task must be understood in terms of the integration of internal and external processes.

1.4 Epistemic Action and Interactive Skill

Considering that actions may be taken to affect the environment in task-relevant ways (Wilson, 2002), such actions may allow the environment to be actively utilised by adapting and changing it to improve its cognitive congeniality, as well as using it to off-load cognitive work. The term environment here is used to refer to *task environments*, defined as micro-environments embedded in the larger environment (Kirsh, 1996), which are part of the problem space.

The off-loading of cognitive work to task environments is achieved by the means of what Kirsh (1995a, 1996, 2006) and Kirsh and Maglio (1992a, 1994) have termed complementary or *epistemic actions*, which increase the speed, accuracy, or robustness of performance, and thus simplify internal cognitive computation (Maglio & Wenger, 2000).

Specifically, the term epistemic action designates a physical action whose primary function is to improve cognition by simplifying computation in three ways (cf. Kirsh & Maglio, 1994, p. 514):

- Reducing the memory involved in mental computation, i.e., space complexity;
- Reducing the number of steps involved in mental computation, i.e., time complexity; and
- Reducing the probability of error of mental computation, i.e., unreliability.

Everyday examples of epistemic actions are things such as using pencil and paper to perform arithmetic such that intermediate results are offloaded from working memory (Kirsh, 1995a), or memory-saving actions like reminding by tying a string around one's finger, or time-saving actions such as preparing a workplace by partially sorting nuts and bolts before beginning an assembly task in order to reduce later search (Kirsh & Maglio, 1994).

Epistemic actions are seen as external components in an interactive computation that serve to complement internal cognitive processes (Kirsh, 1995a). They thus form part of what is termed a 'complementary strategy' towards problem-solving, where such a strategy is defined by Kirsh (1995a) as any organising activity which recruits external elements to reduce cognitive loads. Kirsh (1996, p. 442) defines this strategy more specifically as: "...an interleaved sequence of mental and physical actions that results in a problem being solved – a computation being performed – in a more efficient way than if only the mental or physical actions alone are used," where this increase in efficiency is as a result of the fact that less working memory, less visuospatial memory, less control of attention, and/or less visual search is required when such a strategy is used.

This increase in efficiency leads to increases in performance, particularly for tasks possessing a spatial requirement (Wilson, 2002). Kirsh (1995a) demonstrated this by performing an experiment in which performance was enhanced when participants were allowed to use their hands and fingers to point or count 30 coins, as opposed to when they were not allowed the use of hands and fingers to count the coins. It was discovered not only that the mean time taken to announce the sum was shorter in the 'Hands' compared to the 'No Hands' condition, but also that the error rate, measured as the mean number of mistaken sums, was lower. When participants were allowed to change the arrangement of the coins by physically manipulating them, the error rate was reduced even further (Kirsh, 1995b).

The world thus functions in interaction with the agent (Maglio & Kirsh, 1996), and computation involves an interactive search process in which external, physical activity effectively complements internal, cognitive activity (Maglio, Matlock, Raphaely, Chernicky, & Kirsh, 1999). Skill in any one particular domain is thus seen as *interactive*.

The epistemic action theory avoids many of the criticisms levelled against the broader distributed cognition approach in that it does not actually view the environment as part of the cognitive system, but rather takes the view that cognition can be *off-loaded* to the environment. It also avoids the 'coupling-constitution fallacy' that Adams and Aizawa (2001) suppose many theorists make, in that although coupling is seen as important in the epistemic action view, in terms of this view, coupling does not necessitate the environment forming part of the cognitive system. Rather, the epistemic action viewpoint still holds that certain cognitive processes may be internal, and in fact the essential argument of this viewpoint is that external action *complements* internal computation, by making it easier, faster, and/or more reliable.

1.5 Interactive Skill in Tetris

Most studies of the epistemic benefits of action have involved exploring the way in which expert skill involves agents' control activity – that is, how they use ordinary actions to unearth valuable information that is unavailable, hard to detect, or hard to compute (Kirsh & Maglio, 1994) – within the videogame Tetris, "...a game in which the player attempts to accumulate a high score by the compact placement of geometric objects (zoids) which fall down from the top of the screen" (Clark, 1997, p. 203) (see Maglio & Kirsh, 1996, p. 391 for an explanation of how the game is played).

In the seminal paper *On distinguishing epistemic from pragmatic action*, Kirsh and Maglio (1994) illustrate how a traditional process model of expertise, implemented in a computer programme called RoboTetris, could not account for what on the basis of the traditional model would be considered superfluous actions. In terms of a classical information-processing model of expertise, Tetris-cognition would proceed in four phases, the first of which would be the creation of an early bitmap representation of selected features of the current situation, followed by the encoding of this representation into a more compact, chunked, symbolic representation. Following this is an internal search for the best place to put the zoid, and finally the trajectory of moves to achieve the goal placement is computed. For example, the Tetris display would be encoded in a bitmap-like representation, following which chunks of both the zoid and the contours of the playing field, such as corners and T-junctions, are encoded through selective attention. These chunks then accumulate in working memory where they are compared to identify the best region of the contour on which to place the zoid. Following this, a minimal motor plan is executed which specifies only the actual actions taken to orient and place the zoid in its contour.

On the basis of this model, any actions occurring before the final phase ought to be unplanned, and so should be no better than random actions (Kirsh & Maglio, 1994). The data collected on human players suggested otherwise, as an examination of this data revealed that: "Rotations and translations occur in abundance, almost from the moment a zoid enters the Tetris screen" (Kirsh & Maglio, 1994, p. 523). If rotations were purely pragmatic actions – intentional movements taken to bring the agent physically closer to its external goals (Kirsh, 2006) – the function they would serve would be to orient a zoid, and nothing more. However, Kirsh and Maglio's (1994, cf. pp. 526-539) examination of human Tetris playing suggested that rotation may be used to perform four functions.

The first is to unearth new information very early in the game through rotating zoids that are partially hidden as they enter the field of play, to save mental rotation effort as a result of the fact that it takes less time to physically rotate a zoid than it does to mentally rotate it (100 milliseconds in the former case, 800 to 1200 milliseconds in the latter). The second is to facilitate retrieval of zoids from memory by providing more than one orientation of a zoid, thus providing more than one cue. The third function is to make it easier to identify a zoid's type by reducing the number of attentional probes needed. This is as a result of the fact that if zoid identification is seen as proceeding according to a decision-tree, rotation can provide more information about the zoid and hence reduce the depth of the tree. The final function is to simplify the process of matching a zoid to a contour in the playing field by creating new orientations of the zoid through physical rotation, which is quicker than mental rotation, and these extra orientations therefore facilitate the matching of zoid and contour chunks by generating additional zoid chunks, thus ensuring that enough chunks of different sizes are tested to guarantee finding the largest matching chunks. For example, Maglio and Wenger (2000, 2002) found that physically rotating a zoid was found to increase the number of distinct views that are available as previews, and this decreases the response time needed to make judgements about whether or not a target Tetris piece fits into an accompanying board.

If translations served a purely pragmatic function, it would be to shift a zoid either right or left to permit its placement in a column. However, Kirsh and Maglio (1992b, 1994) discovered that zoids were translated to the wall and then back again to its original position in order to verify its placement in that position, so that it does not land in a mistaken column when dropped, an example of using an epistemic action to reduce the probability of error. This is as a result of the fact that the accuracy of judging spatial relationships between stimuli varies with the distance between the stimuli (Jolicoeur, Ullman, & Mackay, 1991, cited in Kirsh & Maglio, 1994), and thus translation to the wall and back again is usually used when zoids are higher up in the playing field.

Although the study by Kirsh and Maglio (1994) demonstrated that epistemic actions allow individuals to more efficiently distribute work amongst more subsystems (such as perception, memory, etc.), a further study by Maglio, Wenger, and Copeland (2003) not only replicated the results of Maglio and Wenger (2000, 2002), but also supported the hypothesis that the net benefit of performing epistemic actions outweighs the costs. Using the hazard function, defined as "...a conditional probability function that assesses the instantaneous likelihood of completing a process, conditional on not yet having completed the process" (Maglio *et al.,* 2003, p. 753), it was discovered that the previews relieve the player of the need to perform the rotation mentally, allowing more information to be processed in a unit of time.

The fact that performing epistemic action allows more information to be processed more efficiently can explain the finding of Maglio and Kirsh (1996) that individuals more skilled at Tetris take more actions than individuals less skilled at the game, a finding that is in fact counter to the assumption inherent in most theories of skill learning that more skilled agents make fewer redundant actions. Maglio and Kirsh (1996) discovered not only that the number of apparently extraneous actions increases with practice, but also that Tetris skill follows the power law of practice, which states that practice improves performance in accordance with a power function of practice time or practice trials.

1.6 Interactive Skill in Scrabble

Studies in domains other than Tetris have shown that taking extra actions facilitates problem solving. For example, Maglio, Matlock, Raphaely, Chernicky, and Kirsh (1999) examined the use of epistemic actions in an experiment based on the board game Scrabble, in which players form words by arranging tiles with letters printed on them. This study predicted that physical manipulation of the stimuli would aid in the production of words, and was based on the supposition by Kirsh (1995b) that it is easier to form words by physically moving the tiles than by simply imagining their rearrangement. This idea is predicted by the epistemic action hypothesis on the basis that internal computation can be off-loaded to the world through physical action, which would encode needed information more explicitly, thus saving mental computation (Kirsh, 1995b).

For example, as early as 1967, Gavurin noted that anagram solving situations which do not permit overt letter rearrangements should require more spatial aptitude than do situations in which overt letter rearrangement is permitted (Mendelsohn & Covington, 1972). This is as a result of the fact that there is a spatial aspect to anagram solving in that "...the ability to mentally manipulate letters in an anagramming task is, in fact, a visuospatial task because it involves rearranging letters and quickly determining if the possible combinations of adjacent letters yields good possibilities" (Halpern & Wai, 2007, p. 85). Self-reports collected from individuals confirm this, as many individuals report that they attempt to visualise response alternatives by imaginatively shifting around the letters in front of them (Mendelsohn & Covington, 1972). Gavurin discovered that scores on a test of spatial reasoning correlated with the number of anagrams solved, and that this correlation dropped to a non-significant level when participants were allowed to try out solutions by manipulating the tiles on which the letters were printed (Mendelsohn & Covington, 1972). Gavurin thus noted that: "For situations in which overt manipulation is possible ... symbolic reorganisation of the problem stimuli is unnecessary, since this can be accomplished concretely" (Gavurin, 1967, p. 67), in other words, information can be more explicitly encoded.

The study of Maglio *et al.* (1999), being an experimental study, was an improvement over Gavurin's study, which was simply relational. Participants in the study of Maglio *et al.* were tested across two letter strings, and two manipulation conditions: One in which physical manipulation of the tiles was allowed (the 'Hands' condition), in other words, the performance of epistemic actions was allowed; and a second condition in which physical manipulation of the tiles was not allowed (the 'No Hands' condition). Maglio *et al.* discovered that the use of hands increased the number of words produced, and the results of this study can thus be taken as yet more support for the hypothesis that people sometimes take physical actions to improve problem solving (Maglio *et al.*, 1999), especially considering that the instructions to perform epistemic actions does not necessarily result in people performing more of these actions. For example, Maglio *et al.* (1999) noted that even in the 'Hands' condition, roughly one third of the participants chose not to use their hands or used their hands only briefly.

1.7 Overview of the Present Research

The fact that virtually all previous studies on the performance of epistemic actions use spatial tasks is a major methodological weakness, as it prevents one from categorically showing that epistemic actions aid cognition in general, and that they can improve performance at tasks which are not spatial in nature. The study by

Maglio *et al.* (1999) goes some way towards addressing this problem, as anagram solution and the game of Scrabble also requires a verbal aspect in the form of the rapid retrieval of words from the lexicon (Halpern & Wai, 2007). Moreover, the task is likely to load more on the verbal aspect than the visuospatial aspect, as "...familiarity with the language guides successive attempts to rearrange the letters of the anagram into a meaningful word" (Mendelsohn & Covington, 1972, p. 451).

Some attention was given to the verbal aspects of the task in the Maglio *et al.* (1999) study in that an interaction effect between physical manipulation and the letter string used was obtained, such that physical manipulation assisted only for the string that contained words which were far less frequent in both written and spoken English. The experiment conducted by Maglio *et al.* (1999) therefore provides an opportunity to investigate the supposed ubiquity of epistemic actions in improving task performance by examining the effect that they have in the performance of a task which contains an element of processing additional to spatial processing requirements.

In this regard, the present research attempted a cross-linguistic replication of the experiment of Maglio *et al.* (1999), by requiring one group of participants to perform the task in their second language (L2) (Afrikaans in the present study), and comparing the performance of this group to the performance of the group of participants who performed the task in their first language (L1) (English in the present study). The rationale behind this was that requiring participants to perform the task in their second language would most likely accentuate the verbal aspect of the task since verbal processing loads would therefore be greater, as processing in a second language is less automatic (Carr, 1992), and this study would therefore address the gap in the literature concerning the lack of studies on whether or not epistemic actions aid in task performance in tasks that are not spatial in nature. A study such as this would also provide an opportunity for investigating the influence of linguistic factors in the task, as the results of numerous pieces of research (reported in Chapter 2) have demonstrated that cross-language interference effects occur regularly in numerous different tasks. A cross-linguistic replication therefore also provides the opportunity for investigating how these interference effects interact with the performance of epistemic actions, such that in some cases the interference may be reduced, whereas in other cases the interference may actually be enhanced.

The rest of the dissertation is therefore structured as follows: Chapter 2 presents a preliminary model of the way in which epistemic actions may aid (and in some cases impede) performance in the Scrabble task used by Maglio *et al.* (1999). This model is informed by the results of previous research which has been conducted in the domain of anagram solution, as the production of words from a string of letters is essentially a type of anagram solution task. This is as a result of the fact that the letter string presents the participant with a number of possible anagrams that need to be 'solved' in order for words to be produced from a randomly arranged letter string, where the number of words produced from the string can be taken as an indirect measure of the number of anagrams 'solved.' As the present research also involves a cross-linguistic element, the model is also informed by previous research on theories of bilingual lexical access and cross-language interference effects. Chapter 3 presents the attempt at a cross-linguistic replication of the original Maglio *et al.* (1999) study, and Chapter 4 presents a follow-up experiment that was performed on the basis of the results from the first experiment that indicated that the productiveness of the letter strings may be responsible for influencing the epistemic action effect. Finally, Chapter 5 presents a general discussion of the results of both studies, as well as some possible future research that could be conducted in order to investigate the performance of epistemic actions in anagram solution tasks.

1.8 Conclusion

Epistemic action forms part of the broader theoretical framework of distributed cognition, a viewpoint which holds that the environment can form part of, and be involved in, cognition, and cognitive systems as opposed to individual cognition are therefore examined. In this view, cognition is seen as involving an interaction, transaction, and co-ordination with environmental structures such that cognitive agents may become structurally coupled to their environments through the embodied nature of their problem-solving activities.

Viewing cognition as involving an interaction with the environment allows an examination of the way in which actions may be taken to improve the cognitive congeniality of the environment, and the way in which actions may be taken to off-load cognitive work to the environment. Such actions are termed *epistemic actions*, and are actions which serve to reduce the space complexity, time complexity, and/or unreliability of mental computation. The usefulness of such actions was first demonstrated within the domain of the computer game Tetris, although thus far the generalisability of the epistemic action hypothesis seems to be limited to tasks that possess a spatial requirement. Considering that word production tasks also involve a verbal aspect, the study by Maglio *et al.* (1999) addresses this gap slightly. However, given that it seeks to replicate and extend the results of this study across another language, and given that performing the task in a second language is likely to accentuate the verbal requirements of this task, the present research will provide the opportunity for this gap to be more conclusively filled, provided of course that the epistemic action hypothesis can be upheld by the results of the present research.

Chapter 2

Model of Interactive Skill in Scrabble

2.1 Overview

This chapter presents a model of the use of epistemic actions in a Scrabble-like task which is based on the model of epistemic action developed by Kirsh and Maglio (1994, see p. 542). As the current study involves an examination of the effect that epistemic action has when the Scrabble task is performed in a first language and a second, the model also incorporates elements of bilingual lexical access. Furthermore, since rearranging a string of seven letters is essentially an anagram solution task, where the number of words generated can be taken as an index of the amount of solutions accrued throughout the task, it is important to consider the findings of previous research on anagram solution in generating a model of performance in the Scrabble-like task. Pertinent findings from the anagram solution literature are thus incorporated into the model at various stages.

Following Kirsh and Maglio (1994), the model assumes that processing is *cascaded*, such that "...each phase may begin its processing before it has been given all the information it will eventually receive" (p. 524). Thus, although the model is described in terms of distinct phases, each phase can reciprocally influence each other phase, and action can be executed at any phase. Moreover, elements of language interpenetrate each phase, and actions may in turn reciprocally influence the way in which elements of language affect each phase.

The model also incorporates aspects of both serial and parallel processing, as previous research has demonstrated that anagram solution may involve a serial search process in certain instances, a parallel process in other instances, and even a serial process followed by a parallel solution process. For example, Novick and Sherman (2003) found that 47% of solutions to anagram problems in their Experiment 1 were reported by participants as being 'pop-out' solutions (parallel solutions); 26% were incremental solutions (serial solutions); and 27% were mixed solutions, that is, incremental solutions followed by pop-out solutions. Anagrams therefore admit both pop-out and search solutions (Novick & Sherman, 2003). It is therefore important that any adequate model addresses facts such as these. The way in which this is done, is that although the model overall views the process as being cascaded, in certain phases parallel processing is more likely to occur, and in other phases serial processing is more likely to occur. However, more attention is given to how physical manipulation assists a search strategy, as this is the strategy in which it can be expected that manipulation would aid more, as it is in this strategy that individuals usually turn to an actual rearrangement of the letters.

As the current model also seeks to incorporate the verbal aspect of the task, a theory of lexical access, and bilingual lexical access in particular, needs to be considered in building the model. It is therefore necessary to consider these theories first before the model can be fully described in detail.

2.2 Theories of Bilingual Lexical Access

Theories regarding how bilinguals access their lexicon/s can be divided into two distinct viewpoints. The first viewpoint is a selective access view, which posits that bilinguals access their two lexicons selectively; the second viewpoint is a non-selective access view, which posits that bilinguals access the lexical links shared between their two languages (van Heuven, Dijkstra, & Grainger, 1998).

2.2.1 Selective access

If bilinguals access their two lexicons selectively, lexical selection is exclusively confined to the target language. The selective access viewpoint posits that an 'input switch' guides all incoming information to the lexicon of one language, which thus 'turns off' the lexical forms of the inactive language (Gollan & Kroll, 2001; Grainger & Beauvillain, 1987; van Heuven *et al.*, 1998). According to van Heuven *et al.* (1998, p. 458):

> The high selectivity of the system implies that the linguistic input initially (i.e., at the orthographic or phonological level) only contacts representations in one language. If the lexical representation corresponding to the input is not found in the active lexicon, contact is established with the other lexical system.

In terms of this view, the language mode that an individual is operating in at any one particular time allows a pre-selection of the lexical system to be accessed (Grainger & Beauvillain, 1987). Intrusions from the non-target language would thus be prevented, and would therefore not be able to interfere during lexical access (Costa & Santesteban, 2004). Support for this view stems from the fact that fluent bilinguals are able to function exclusively in a single language system, and this is viewed as evidence of the fact that control over access to one lexical system can be exercised (Grainger & Beauvillain, 1987).

Research addressing the issue of an 'input switch' has discovered that switching from one language to another seems to indicate that extra processing time is required, and this requirement is seen as indicative of the fact that switching induces an extra processing load. For example, Macnamara and Kushnir (1971, cited in van Heuven *et al.*, 1998) discovered that switching languages within English and French mixed-language sentences takes time compared to monolingual sentences.

Rather than using a switching paradigm, Gerard and Scarborough (1989, cited in Marian, Spivey, & Hirsch, 2002) found that significantly less time is required to make a judgement in a lexical decision task involving homographs (words that have the same spelling but differ in meaning, e.g. *fair*, meaning 'pleasant in appearance' or 'market') following a same-language as opposed to a different-language repetition. Using the notion that the log-frequency of a printed word is a predictor of the time required to recognise that word, Gerard and Scarborough reasoned that if lexical retrieval is non-selective, then the time taken to recognise homographs would depend on the overall familiarity of these spelling patterns in both languages, rather than the frequency of use in the currently active language (French & Ohnesorg, 1995). They discovered that word frequency in the currently active language, not the overall frequency in both languages, predicts homograph recognition time (French &

Ohnesorg, 1995), thus suggesting that the bilinguals were functioning as English monolinguals (van Heuven *et al.*, 1998).

The results of Experiment 2 of Costa, Miozza, and Caramazza (1999), a picture-word interference experiment in which Catalan-Spanish bilinguals named pictures in Catalan with distractor words printed in either same- (e.g. *taula-taula, table* in Catalan) or different-language pairs (e.g. *taula-mesa, table* in Spanish) also support the hypothesis of language-specific selection. Costa *et al.* discovered that semantically related distractors in both the same- and different-language conditions were similarly interfering, and take this result as support for a selective access model, as according to a non-selective access model interference should only occur cross-language, in other words only in the different-language condition. They conclude on the basis of this that "...even when maximizing the opportunity for competition between languages, it seems that balanced bilinguals can restrict lexical access to one of their two lexicons" (p. 375).

Studies of the neural organisation of bilingualism have revealed similar findings, with selective impairment of one or more languages in multilingual aphasic patients, selective disruption of first or second naming in cortical simulation studies, and different Event Related Potential patterns in first language processing of bilinguals and monolinguals all being reported in previous research (Marian *et al.*, 2003).

2.2.2 Non-selective access

Most studies to date have proven that lexical access in bilinguals is in fact non-selective. According to Kroll, Michael, Tokowicz, and Dufour (2002), the non-selective access viewpoint suggests that lexical candidates are routinely activated in L1 when words in L2 are produced. Accordingly, the lexical selection mechanism is insensitive to the target language that an individual is operating in (Grainger & Beauvillain, 1987) such that stimuli activate words from both languages during the recognition process (van Heuven *et al.*,1998). A person will therefore "...consider for selection all activated lexical nodes, irrespective of the language to which they belong, and successful selection of the proper lexical node (i.e., in the correct language) is achieved by creating a differential level of activation in the two lexicons of a bilingual" (Costa & Santesteban, 2004, p. 492).

Support for the non-selective access view comes from a study by Dijkstra, Timmermans, and Schriefers (2000), who report results which essentially contradict those discovered by Gerard and Scarborough (1989, cited in Marian *et al.*, 2002) that were taken to indicate that bilingual lexical access is non-selective. Experiment 1 of Dijkstra *et al.* used a language decision task involving interlingual homographs in Dutch and English, words which are form-identical but differ in meaning across languages (e.g. *list* means 'trick' or 'guile' in Dutch). According to Dijkstra *et al.*, if bilingual lexical access is selective, an interlingual homograph should activate its reading in the target language only, and would thus be recognised as fast as a frequency-matched control item existing exclusively in one language, whereas if access is non-selective, both readings of the homograph will be activated in parallel.

Not only did the authors find that fewer 'English' responses and slower reaction times compared to matched exclusively English controls were obtained, but also that the Dutch-English frequency ratio of the two readings of a homograph affected not only language choice but also response latency. On the basis of these results, Dijkstra *et al.* state that: "It is difficult to imagine how participants could perform language decision (Experiment 1) under a language-selective view and still produce frequency-dependent cross-language effects" (p. 460). This conclusion is supported by the results of their Experiments 2 and 3, which used a language go/no-go paradigm, in which participants must respond only when a presented word belongs to a specified target language. The results of these experiments indicated that frequency effects of interlingual homographs affect reaction time in this paradigm as well, and this provides clear evidence of effects of the non-target language reading on homograph recognition, effects which are not predicted by the selective access view as in terms of this theory, only the target-language frequency of the homograph should be relevant (Dijkstra *et al.*, 2000; Gerard & Scarborough, 1989, cited in Marian *et al.*, 2002).

Using the paradigm of eye-tracking, Marian *et al.* (2002) tested spoken language processing in bilinguals with the aim of examining whether both languages are activated in parallel or separately. Based on previous research with monolingual speakers which found that listeners frequently look briefly at a 'cohort' object with a phonologically similar name when instructed to pick up a target object (e.g. a candle when instructed to pick up candy), Marian *et al.* gave participants instructions in one language and recorded when their eyes fixated the target object, a between-language cohort, and a non-overlapping control distractor object. In all three of their experiments, individuals made significantly more eye movements to the between-language competitor than to the control object in the same location, and the authors interpret these results as demonstrating that "...between-language competition is possible from both languages and into both languages" (p. 75).

Between-language competition was also investigated in a series of experiments involving different tasks and conditions by van Heuven *et al.* (1998), taking the number of orthographic neighbours of a word as an index of the influence of non-target language words on target word recognition, and using this to test between the selective and non-selective access views. According to these authors, the selective access hypothesis predicts that recognition of a target word is influenced only by the neighbourhood characteristics of the target language, whereas a non-selective view posits that neighbourhood effects of both languages would occur during the recognition process. In their Experiments 1 to 3, van Heuven *et al.* conclusively demonstrated that both within- and between-language manipulations of orthographic neighbourhood density influenced performance in bilingual participants not only in a lexical decision task, but also in a progressive demasking task, a task in which the presentation of the target word is alternated with that of a mask, where the target presentation time slowly increases while that of the mask decreases. Furthermore, the results of their Experiment 4 indicated that the between-language effect disappeared in a monolingual control group. The results of these experiments can therefore be taken as additional support for the hypothesis of non-selective access.

In terms of the neural organisation of bilingualism, results which contradict the findings that one language can be selectively impaired have been discovered. Event Related Potential, Positron Emission Tomography, and functional Magnetic Resonance Imaging studies have all found that the same brain regions may be activated for both languages in bilinguals (Marian *et al.*, 2002).

Although much of the current research in the field of bilingual lexical access has tended towards the support of a non-selective access hypothesis, the issue is complicated by the hypothesis that bilinguals, even assuming a non-selective view, can control at least slightly the level of activation in their two lexicons by entering into one 'language mode' (Dijkstra *et al.*, 2000; Grainger & Beauvillain, 1987). More specifically, this is a "...non-selective access view assuming that the bottom-up activity generated by the input string can be modulated by top-down factors such as the participant's (strategic) compliance with task demands or the specifics of the instructions" (Dijkstra *et al.*, 2000).

Costa and Santesteban (2004) put forward the 'language-specific selection threshold hypothesis' to account for the findings in some of their experiments that highly proficient bilinguals are slower in their dominant than in their non-dominant language in a language switching task, where participants are required to switch between their first and second languages. The hypothesis is that participants can use information about the task demands to manipulate the level of activation of the two lexicons, creating an imbalance between them which would in turn lead to faster selection of L2 words. Certain of the results obtained by Dijkstra *et al.* (2000) contradict this finding, in that in the go/no-go task (see above) they discovered that participants were not capable of achieving optimal performance by suppressing the non-target language, even when the task was performed entirely in participants' first language. Similarly, the results of the three experiments performed by Marian *et al.* (2002) suggest that: "Bilinguals appear to simultaneously accumulate phonetic input into both of their lexicons as a word unfolds in real time, even when the linguistic environment is purely monolingual" (p. 75). Thus, bilinguals do not seem to be able to control where along the monolingual/bilingual mode continuum they position themselves, and seem to be restricted by the language characteristics of the stimuli (Dijkstra *et al.*, 2000; Grainger & Beauvillain, 1987).

A finding in the study by Costa and Santesteban (2004) may resolve this seeming inconsistency between their results and those of Dijkstra *et al.* (2000), in that they discovered that asymmetrical switching costs, whereby it is harder to switch into the dominant language than to the weaker language, are present for L2 *learners*, but not for *highly proficient* bilinguals. Similarly, Costa *et al.* (1999) found that balanced bilinguals can restrict access to one of their two lexicons. The reason Costa and Santesteban (2004) give to account for findings such as these is that the lexical selection mechanism of L2 learners relies on inhibitory control, in which a differential amount of inhibition in the one language relative to the other ensures selection in the intended language, whereas the lexical selection mechanism of bilinguals who have achieved a high proficiency level in any pair of languages is lexicon-specific. Thus, "...an increase in the proficiency level of the bilingual speaker would lead to a shift in the 'type' of processes responsible for focusing on one language" (Costa & Santesteban, 2004, p. 505). In other words, more skilled bilinguals are able to control access to their two lexicons in a more skilled manner.

On the basis of the fact that recent studies have tended to support a non-selective over a selective access viewpoint, a non-selective active viewpoint was adopted in the current model of interactive skill in Scrabble. This model is now described in detail below.

2.3 The Current Model

Following Halpern and Wai (2007), the model is based on the assumption that anagram solving can be seen as a generate and test process in which common letter sequences are generated and then tested to determine if the possible combination of adjacent letters yields good possibilities, and describes how this generation and testing occurs by appealing to the literature on anagram solution. The model is conceived in terms of four primary phases which occur during the performance of the task. In the first phase, selective attention is applied to the task. In the second phase, the presented letter string floods the iconic buffer, and a number of what are termed 'pop-out' solutions occur. In the third phase, the number of pop-out solutions becomes exhausted, and a letter re-arrangement strategy is entered into in which letter chunks are extracted from the string. The final phase involves a search through the lexicon such that these chunks are tested against legal words to determine if their combination yields good possibilities. The model is represented diagrammatically in Figure 1 below, which is adapted from Kirsh and Maglio (1994, p. 542).

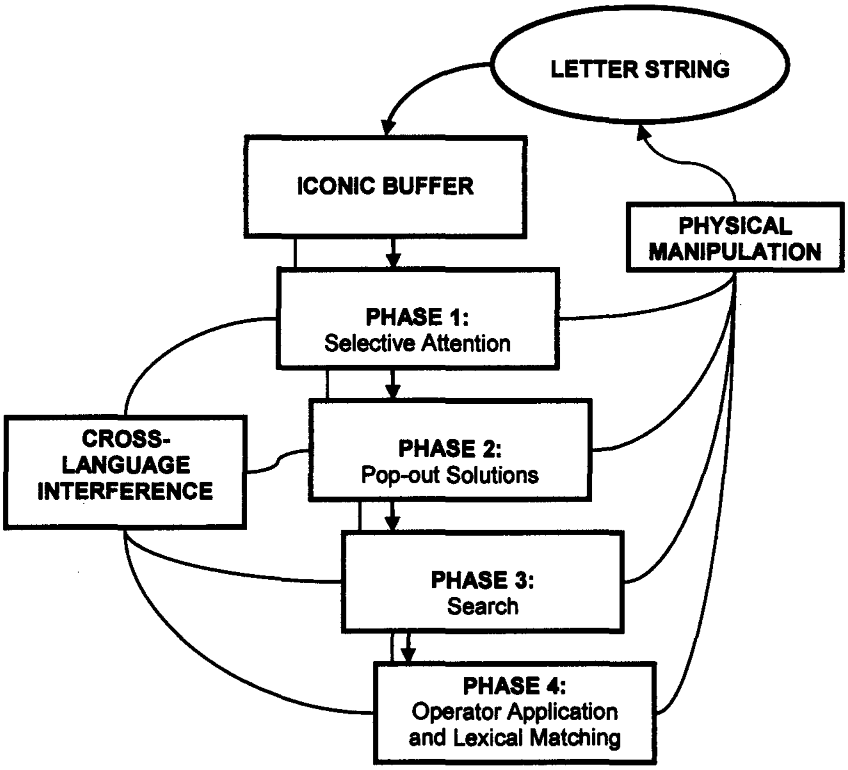

Figure 1. In this model, physical manipulation can influence all four phases, and cross-language interference can be expected at each of the four phases. Furthermore, physical manipulation of the letter string can influence and change the cross-language interference effects. Adapted from "On distinguishing epistemic from pragmatic action," by D. Kirsh and P. Maglio, 1994, *Cognitive Science, 18,* p. 542.

2.3.1 Phase 1: The Application of Selective Attention

In the first phase of the model, attention is focused on the presented letter string which then floods the iconic buffer of working memory. The contents of the iconic buffer are similar to maps, in which important visual features are present but not encoded symbolically (Kirsh & Maglio, 1994). Linguistic resources are important in the performance of the task as these resources are said to better enable us to control the disposition of selective attention to ever-more complex feature combinations (Clark, 2005b). Assuming a non-selective access viewpoint, even from the very initial phase of this model we would expect interference effects from the first language into the second on the basis of the fact that competition from both languages and between both languages is possible (Marian *et al.*, 2002). This interference is likely to be greater when the task is performed in a second language as a result of the fact that attentional processes are usually biased towards, and by, an individual's first language. Slobin (1996, cited in Segalowitz & Frenkial-Fishman, 2005) has argued that adults find automatising attention difficult within a second language, as each native language has trained its speakers to pay different kinds of attention to events and experiences when talking about them and this training is extremely resistant to restructuring in L2 acquisition.

In addition, the level of attentional involvement needed is reduced the more familiar an individual is with a particular language. For example, a study by Givon, Yang, and Gernsbacher (1990, cited in Carr, 1992) compared native English-speaking undergraduates early and later in the learning of Spanish using the tachistoscopic report task with peripheral spatial cueing developed by Sieroff and Posner, a task in which cues on the left and right of foveally centred letter strings are used to bias spatial attention (Sieroff & Posner, 1988). It was discovered that when the letter strings to be reported were Spanish words, beginning students showed neglect of letters on the side away from the cue, whereas more experienced students did not (Carr, 1992). Carr (1992) takes this result to indicate that as unitised lexical representations become established in the visual word processing system, the need for attentional supervision may decline, and thus more familiar words are processed via an automatic, stimulus-driven route. Similarly, a study by Gernsbacher (1984) discovered that lexical familiarity, operationalised as rated experiential familiarity, greatly affected reaction times on a lexical decision task, and in fact accounted for 71% of the variance found in performance.

A high level of attentional involvement is therefore necessary for less familiar letter strings, and the need for it is reduced or its operation made more efficient "...when stimuli are familiar or well structured enough to have directly activatable or easily computable unitised representations available in the visual word form system" (Carr, 1992, p. 220). Unitised representations formed as a result of greater familiarity with a language may therefore extend the range of general and overall attentional deployment (Carr, 1992).

Even in this early stage of the model then, the attentional biases created by the L1 will bias an individual towards words that can be made in that language from the given set of letters. In addition, when the task is performed in a second language a greater demand is placed on the attentional system, such that the additional attentional resources required for second language processing compete with the attentional resources required for adequately performing the task itself.

2.3.2 Phase 2: The Generation of 'Pop-out' Solutions

Based on previous research by Kaplan and Carvellas (1968, cited in Gavurin & Zangrillo, 1975) that found that participants initially try to solve anagrams without rearranging the letters (a whole-word strategy; Furby, 1977), a whole-word solution strategy is likely to occur in this phase. Similarly, recent research by Novick and Sherman (2003) on anagram solving suggests that a lot of very fast solutions occur initially, but that there is a steady drop-off in solutions from a time period as short as 30 seconds into the task. Their intuition is that these very fast solutions are 'pop-out' solutions, solutions which pop into mind suddenly and fully intact after about two seconds, and that the remainder of the solutions are search solutions, incremental solutions obtained via a "...search through a space of possible intermediate problem states for a path leading from the initial state to the goal" (Novick & Sherman, 2003, p. 352). Even in this early phase, physical manipulation of the letter string may aid in word generation simply by allowing individuals to randomly rearrange the string, as this would change the originally presented order, allowing a new sequence of pop-out solutions to occur. This is as a result of the fact that individuals often perseverate on the presented order when it seems word-like, thereby slowing down the process of breaking apart that order in order to facilitate solution (Novick & Sherman, 2007). When trapped in the original arrangement of the letters in this way, physically reorganising the tiles can provide an element of randomness which can assist internal search, in other words, individuals can escape local minima in the search space (Maglio *et al.*, 1999). Early support for this hypothesis comes from a study by Gavurin (1967) which found that anagram solving is facilitated if the letters are repeatedly rearranged in a random fashion. Wallace (1979) subsequently replicated this result, and hence stated: "...anagram-solvers can apparently increase their chances of success by effecting repeated random rearrangements of the letters" (p. 72).

Supposing that this rearrangement takes place in working memory, allowing this re-arrangement to take place through physical manipulation saves mental rearrangement effort. In this case, however, it can be expected that the relative contribution of physical manipulation would be low, as the chance of rearranging the letters into a true word is small.

Bigram effects become important in this phase of the model as recent research by Novick and Sherman (2007) has demonstrated that bigram frequencies predict the occurrence of pop-out solutions. When considering common letter pairs, it is therefore important to consider the letter transition probability (LTP) of the anagram stimulus. According to Pinckney and Kwiatkowski (1977), the frequency with which a letter follows or precedes another letter can be determined by consulting tables provided by researchers. By totalling the numerical values assigned to such two-letter groupings a frequency count, or transitional total for the full array of letters constituting a word or anagram developed from a word can be arrived at. Pinckney and Kwiatkowski take this total frequency count as an operational definition of transitional probability.

Language becomes important here in that implicit knowledge of letter transition probabilities in a particular language leads individuals to rule out highly unlikely sequences and to begin by trying sequences which have a high frequency of occurrence (Furby, 1977), as individuals tend to consider only those combinations of letters which their knowledge of the language leads them to believe to be probable (Wallace, 1979). This actually makes anagrams of a high LTP more difficult to solve than anagrams of a low LTP, as according to Pinckney and Kwiatkowski (1977), it is easier to break up letter combinations that seldom occur than it is to rearrange more commonly occurring letter pairs.

An early study by Stachnik (1963, cited in Pinckney and Kwiatkowski, 1977), alludes to the fact that off-loading cognitive resources to the environment may aid in anagram solution in this respect. Stachnik examined whether or not it was more difficult to solve anagrams with a high versus low LTP, and discovered no difference between the two conditions. This was attributed to the fact that participants had a tendency to attempt trial and error solutions on the paper provided, thus allowing them to change the LTP total for the anagrams.

In a study which involving a comparison of one group of participants given scrap paper on which to attempt solutions with a second group in which no paper was provided, Pinckney and Kwiatkowski (1977) could not replicate this finding as they did not discover a significant difference between the groups in terms of the mean number of anagrams solved. Wallace (1977, 1979) notes, however, that the use of pencil and paper to effect solutions may be a less adequate substitute than the physical rearrangement of tiles with the letters printed on them. Moreover, the study by Pinckney and Kwiatkowski examined the solution of whole-word anagrams (where the stimulus is a word; Furby, 1977), and not the solution of nonsense anagrams, where the stimulus is a random arrangement of letters which excludes legal words (Furby, 1977). Attempting trial and error solutions on paper is also a qualitatively different method of off-loading cognitive resources to the environment than physically rearranging the letters that constitute the anagram.

Physical rearrangement of the letters may thus aid in word production in that physical rearrangement would allow individuals to physically break up commonly occurring letter pairs, which may also be done mentally but is more difficult due to the bias that individuals have towards focusing on highly probable letter combinations. Furthermore, new letter combinations can be brought in through the visual system rather than via internally creating them. However, given the conflicting results of the studies listed above on the influence that rearrangement has on affecting LTP totals, the relative contribution that physical manipulation makes in this case may be quite small. In terms of the relative influence of a second language on performance of the task, the contribution of physical manipulation may be more as a result of the fact that since a second language is less familiar, far more high than low probability letter combinations are initially considered. However, the opposite possibility may exist in the sense that since familiarity with commonly occurring letter pairs in a second language is lower, individuals are less implicitly aware of which pairs of letters are of a high and low occurrence, and may therefore begin by considering any pair of letters. In this case, the performance of physical manipulation would have a null effect.

Another possible way in which physical manipulation may help in this phase of the model is as a result of the fact that pop-out solutions occur as the result of a parallel constraint satisfaction process (Novick & Sherman, 2003), which is moreover one of letter rearrangement (Novick & Sherman, 2007). Specifically, pop-out solutions rely more on pattern recognition, of which word recognition is one type, and this is believed to involve parallel processing of the letters (Novick & Sherman, 2003). This phase of the model also involves lexical selection, as this is "...the suppression of active candidates that fail to match the sensory input and/or semantic context" (Aydelott & Bates, 2004, p. 31). In other words, candidates which pop-out but which do not match a word that is legally producible from the letter string need to be suppressed.

An example of a theory which assumes parallel processing of letters is the Interactive Activation model of McClelland and Rumelhart (1981). This model posits the existence of an internal lexicon comprised of specific word codes, and the successful discrimination of words reflects the activation above a criterion level of the word's code (Binder *et al.*, 2003). McClelland and Rumelhart (1981, p. 376) summarise their model as follows:

> The basic idea is that the presentation of a string of letters begins the process of activating detectors for letters that are consistent with the visual input. As these activations grow stronger, they begin to activate detectors for words that are consistent with the letters, if there are any. The active word detectors then produce feedback, which reinforces the activations of the detectors for the letters in the word.

To adapt an example from Chemero (1998), if you are presented with the stimulus 'U E O S H,' randomly rearranging the letters to 'H U O S E' makes it far easier to complete the pattern and allow the word 'HOUSE' to pop-out. In the first case, the time taken to settle on the target is some finite value t, whereas in the second arrangement the time taken to settle on the target is quicker, say $t - a$ (see, for example, Kirsh & Maglio, 1994, pp. 533-534). Empirical support for this hypothesis comes from a study by Novick and Sherman (2003), who found that nearly 50% of the solutions to 'E A H C B' (*beach*) and 'A M F R E' (*frame*) were generated within two seconds. However, only 5% of the solutions to 'C B E H A' and 'R F M E A' were generated within two seconds.

Frequency effects are predicted slightly in this phase in that more common words are more likely to pop-out than uncommon words, although structural factors appear to over-ride frequency effects in importance (Novick & Sherman, 2007). Finally, length effects are also predicted in the first phase of the model, as a study by Kaplan and Carvellas (1968, cited in Gavurin & Zangrillo, 1975) found that the initial tendency of their participants to attempt anagram solution without rearranging the letters resulted in the solution of most of the shorter anagrams. In this sense, the words that are produced via pop-out solutions are likely to be shorter in length than the words that are produced via a rearrangement strategy. In addition, research by Novick and Sherman (2007) discovered that spelling patterns containing one syllable influence the number of pop-out solutions, and one syllable words are likely to be shorter than words with two or more syllables.

2.3.3 Phase 3: The Search Process

According to Novick and Sherman (2003), anagrams allow both pop-out and search routes to solution. In this next phase of the model, the number of pop-out solutions that occur reach a level of exhaustion, and a letter rearrangement strategy involving search is entered into. This phase would most likely occur after about two seconds, as according to Novick and Sherman (2003) this is the time period after which the number of pop-out solutions is exhausted, for both experts and non-experts at anagram solution. This exhaustion occurs as a result of the fact that only a certain number of words producible from the letter string in its originally presented order would provide a good fit to the constraints of the spelling of the language in which the task is performed. According to Novick and Sherman (2003), a parallel letter rearrangement process that tries to best order the letters to satisfy the constraints of the spelling of a particular language would not succeed if the words producible from the letter string are unlikely, as the best fitting letter order generated by such a process would not be a word. In this case, individuals would have to switch to a search process in order to generate words.

This phase would involve the extraction of task-relevant chunks in order to effect this search, where chunks are defined as organised or structured collections of features which regularly recur in a task (Kirsh & Maglio, 1994). Previous research on anagram solution has demonstrated that these chunks may be either single, beginning letters of words (e.g., Witte & Freund, 2001), or may involve common pairs (bigrams), as anagram solution involves the retrieval of common letter pairs from memory (Novick & Sherman, 2003).

It is likely that search may begin with the selection of single letters as a study by Kahneman and Tversky (1972, cited in Halpern & Wai, 2007) found that people are better at generating words that begin with a given letter (e.g., *k*ing) than words that have that letter in the third position (e.g., ma*k*e) because words are often retrieved by their initial letter. In fact, self-reports collected from solvers suggest that individuals often select a single letter as the beginning of the solution word, and then rearrange the remaining letters (Witte and Freund, 2001). Witte and Freund (2001) note that certain studies have discovered that presenting the first letter of the solution word facilitated solution and the results of their Experiment 1 essentially replicate this finding. In addition, a recent study by Novick and Sherman (2007) found in a regression analysis that first letter reliably predicts anagram solution. This could be as a result of the fact that during early visual analysis of text, the positions of the first and last letters of a word are rigidly encoded (Cornelissen *et al.*, 1998) and findings such as these probably reflect the fact that the lexicon is organised in terms of first letters (Kelly & Martin, 1994).

Search strategies deposit their intermediate results in working memory (Novick & Sherman, 2003), and it is therefore in a search strategy that it can be expected that the contribution of manipulation to word production would be greater, as the intermediate results of this strategy could be deposited in the external world through physical manipulation, thus saving working memory resources. In this sense, performing epistemic actions would aid in this task in that the possible chunks of single letters and letter combinations do not have to be held in working memory, which needs to be constantly refreshed every 200 milliseconds (Kirsh & Maglio, 1994), but rather physical rearrangement of the letters can allow the individual to physically form the combinations, leaving them in the external world. For example, in terms of the fact that individuals usually begin solution with the first letter of the solution word such that more possibilities are opened, manipulation would allow the individual to physically fix one letter (the first, or last, or both), placing it completely out of memory and into the visual store. For example, given a string of seven letters such as 'A T B R O S E,' the letter 'B' could be physically fixed and then the words *bat, bet, brat, bore* and so on generated. This would thus save working memory resources by reducing the number of attentional probes needed to constantly refresh the buffer.

In addition to single-letter chunks, bigram chunks are also likely to be extracted. Thus, as with the generation of pop-out solutions, physical manipulation can aid here by allowing individuals to more easily break up commonly occurring letter pairs. This would facilitate the extraction of new bigram chunks from the letter string, thus aiding in search.

Phase 4: The Application of Operators to, and Matching of, Chunks to Words in the Lexicon

After the chunks are extracted from the letter string the search process proceeds through the application of certain operators. Following Maglio *et al.* (1999), seven of these operators can be distinguished. These include the addition, substitution, deletion, and rearrangement of single letters. In addition, they include a type of reversal and special rearrangement, as well appending bigrams and rearranging bigrams. Examples of these seven operators (from Maglio *et al.*, 1999) for English are given below:

1. EAR → BEAR – *arbitrary add*
2. AGO → AGE – *arbitrary substitute*
3. BEAR → EAR – *arbitrary delete*
4. BEAR → BARE – *arbitrary rearrange*
5. GOB → BOG – *reversal, special rearrange*
6. BAR → BARGE – *append bigram*
7. R*AGE* → *GE*AR – *rearrange bigram*

Here, we could expect epistemic action to aid in performance in that rather than applying these operators mentally, they can be applied physically with less computational cost. Physical manipulation can therefore help in providing the input to facilitate a match of the candidate letter combinations to a word in the lexicon. However, physical manipulation is likely to aid more in the applications of certain operators rather than others. For example, in the case of operators 1 and 6, which are reasonably simple to perform, it is likely that they may be able to be applied mentally with equal or even less computational cost than would be involved in applying them physically. It therefore cannot be said with certainty that all of the operators putatively involved in the matching of words to the lexicon would facilitate performance if done by means of epistemic action.

This phase therefore involves the application of the above operators to the single letters or letter pair chunks in order to form possible words, and then the testing of these chunks and possible words against words in the lexicon to determine if the combination of the chunks via the application of the operators would yield a legal word.

In this phase of the model, processing is more likely to involve a serial, incremental search, rather than the parallel process that operates in pop-out solutions. In terms of the serial model of anagram solution of Mendelsohn (1976), hypotheses about the correct letter order based on the judged likelihood of each possible bigram are formed in terms of decreasing order of bigram frequency. These hypotheses are then tested by retrieving words from the lexicon that match the hypothesised partial re-organisation of the anagram. Alternatively, the rearrangement of the remaining (i.e., non-initial) letters of the anagram is effected in an attempt to find a match between the candidate solutions and entries in the lexicon (Novick & Cote, 1992). In this case, physical manipulation would help in the sense that the initial letter of the word would be able to be placed out of memory and into the visual store, and then the remaining letters could also be rearranged physically via the physical, as opposed to mental, application of the above operators. For example, given a letter string such as 'R E A B', the letter 'B' could be placed in the initial position, and the remaining letters rearranged to form the word 'BEAR.' From this word, the letters could then be rearranged again in order to form the word 'BARE.'

Another possible way in which solution may proceed is through the formation of letter clusters of increasing size until a word is created, where different clusterings are explored to different depths depending on such constraints as rules of spelling (Novick & Cote, 1992). Although the clustering of the letters happens in parallel, the progression from letter to bigram to syllable to word occurs serially (Novick & Cote, 1992). In this strategy, physical manipulation would help by allowing the clusterings to be placed in the external world rather then held in internal working memory. This would allow not only the first letter of the word, but also a bigram chunk to placed and fixed in the external world, and rearrangement of the remaining letters around these chunks to be effected.

In a search process of anagram solution, not only orthographic neighbourhood effects, but also frequency effects, are apparent (Novick & Sherman, 2007). In terms of the model presented in this chapter, the two are inter-related via the effect that physical manipulation can have on one (orthographic neighbourhood), and how this may aid in the production of words from a letter string that is of a lower frequency.

This is as a result of the fact that the current model incorporates aspects of the interactive activation model of McClelland and Rumelhart (1981). In terms of that model, orthographic neighbours, which are words that share all but one letter with another word (for example, HOUSE is an orthographic neighbour of HORSE), have a facilitatory effect on the recognition of words as the neighbours of a word are partially activated when the stimulus word is presented, and activation of the orthographic neighbourhood speeds acceptance of the stimulus as a word (Andrews, 1997; Binder *et al.*, 2003). Activated neighbours send inhibitory input to other word nodes (Binder *et al.*, 2003), thus suppressing them, and in the absence of input from its neighbours, nodes in the network are assumed to decay back to an inactive state (McClelland & Rumelhart, 1981). Thus, neighbour activation increases the value of the activity of word nodes, such that a word with many activated neighbours yields higher overall lexical activity (Andrews, 1997).

By physically manipulating the letters in an anagram task, the neighbourhood density of the original arrangement of the letters can be changed, which would then have the effect of increasing the summed lexical activity, which would then speed acceptance of the rearranged letter string as a word. Physical manipulation may thus increase the chance of recognising a word through allowing word recognition to converge by manipulation of the orthographic neighbourhood of the letter string.

Frequency effects are predicted in this phase of the model as words of a lower frequency have lower average resting levels of activations and thus require more activation to push them above the recognition threshold (McClelland & Rumelhart, 1981). This was reported as early as 1951 by Howes and Solomon (1951, cited in McGinnies, Comer, & Lacey, 1952), who "...have demonstrated that visual-recognition thresholds for tachistoscopically presented words approximate a linear, decreasing function of the logarithm of the frequency of usage" (p. 65), in other words, an increase in frequency lowers the threshold of recognition of words. Neighbours therefore have more of a facilitatory effect on the recognition of low as opposed to high frequency words (Andrews, 1997; Binder *et al.*, 2003). Recently, Experiment 2 of Witte and Freund (2001), which examined the effects of four types of retrieval cues (first, middle, or last letter, or no cue) upon solving consonant-beginning words, demonstrated that anagrams forming high frequency words were solved more easily than low frequency words.

Convergence by manipulation of orthographic neighbourhood is thus more likely to help when the words producible from a particular letter set are of a lower frequency than a higher frequency. This is predicted based on a finding in Maglio *et al.* (1999). Using two different strings as stimuli, it was discovered that the use of hands helped with word production only for the string that contained words that were less frequent in both written and spoken English.

Between-language effects can be explained here by the Bilingual Interactive Activation (BIA) model, a bilingual extension of the monolingual Interactive Activation model of McClelland and Rumelhart (1981). The BIA model is of particular relevance for the present research in that it was developed to explain English-Dutch bilingual lexical access, and Afrikaans is derived in part from Dutch (Penn, Venter, & Ogilvy, 2001). In terms of the BIA model, lexical access is non-selective in that activation of a target item is said to be initially affected by lexical candidates from both languages (Dijkstra *et al.*, 2000). In terms of the relative resting levels of activation, lexical candidates in L2 have lower average resting levels compared to candidates in L1, as a result of the reduced exposure of bilingual readers to L2 relative to L1 words; L1 words are therefore activated earlier in the recognition process (van Heuven *et al.*, 1998).

Four possibilities arise as a result of this. The first is that performing epistemic actions can increase the neighbourhood density of the L2 words contained in a presented letter string, thus facilitating the activation of L2 words by increasing their activation level and thus pushing them above the threshold of activation. Since L2 words are assumed to have lower average resting levels of activation to begin with, we would expect the performance of epistemic actions to have more of an effect when an anagram solution, word generation task is performed in a second language. The second possibility is that performing epistemic actions may decrease the neighbourhood density of the L1 words contained in any one particular letter string. This would have the result of reducing the inhibitory effect of L1 on L2 words contained in the letter string, and in this way the formation of L2 words would be indirectly facilitated. The third possibility is a combination of the first two, that is, that performing epistemic actions increases the neighbourhood density of L2 words at the same time that it decreases the neighbourhood density of L1 words. In this scenario, word generation when the task is performed in a second language would be facilitated the most.

The first three possibilities presented above relate to how physical manipulation may facilitate the generation of L2 words. The fourth possibility considers the opposite, that is, that physical manipulation may actually *inhibit* the production of L2 words. This is due to the finding by van Heuven *et al.* (1998) in their experiments that between-language orthographic neighbourhood effects were always stronger in L2 target words than in L1 target words. Specifically, increasing the amount of orthographic neighbours in L1 produces an inhibitory effect on L2, as according to the BIA model L2 target words will also activate L1 neighbours, which in turn activate the L1 language node which therefore inhibits all L2 words. For example, the Afrikaans word *kat* (*cat* in English) would activate not only its Afrikaans neighbours (e.g., *kar*; *car* in English) but also the English word *cat*. Activation of this word would then activate its neighbours, such as *car* as well, and this would in turn increase activation of the English language node which would then even further decrease activation of the Afrikaans language node. In this case, physical manipulation may actually *increase* the time taken to settle on a particular second language target by increasing the activation level of a first language competitor target, rather than decreasing the time taken as is the case in L1.

Language effects also enter into this final phase of the model in terms of the fact that they may affect the application of certain of the operators. For example, orthographic neighbourhood effects are expected for the operator of *arbitrary substitute* in which one letter is substituted for another, as orthographic neighbours are words that share all but one letter with another word. Neighbourhood effects may also come into play with *arbitrary add* in terms of priming effects from high activation neighbours, for example, an "If only I had an 'E' I would have that word" sort of effect may arise. Bigram effects would influence the operators of *append* and *rearrange bigram* in terms of the LTP totals of the bigrams, as these totals determine how easy or difficult it is to break up certain letter combinations. After these combinations are generated, it is required that they be broken up in order for the generation of new words to occur. Physical manipulation would allow bigrams that are more difficult to break up mentally to be broken up physically, thus aiding in word generation.

2.4 Conclusion

This chapter provides a model of task performance in the interactive Scrabble task by taking into account findings from the literature on anagram solution. In the model, word generation is said to proceed through four phases, beginning with attention being directed to the letter string. Following this, a number of very quick pop-out solutions occur, but the amount of these solutions becomes exhausted after about 2 seconds. After this, a search strategy is adopted by individuals. This strategy involves the extraction of task-relevant chunks from the letter string. These chunks most likely include single letters as well as particular letter combinations (bigrams). These chunks are then tested against words in the lexicon to see if their combination yields good possibilities. As the model is cascaded, however, these phases do not necessarily proceed in a linear fashion. For example, a rearrangement strategy may be adopted first, and the rearrangement of the letters may effect a number of pop-out solutions occurring, after which a search strategy would be entered into again. At each stage of the model, physical manipulation of the letters may aid in word generation. Furthermore, as the task is essentially verbal in nature, language can influence performance in the task at any stage, particularly in the form of interference effects from one language into the other when the task is performed in a second language. The next chapter presents the first experiment in the present study, which aimed at a cross-linguistic replication of the original Maglio *et al.* (1999) study described in Chapter 1.

Chapter 3

Experiment 1

3.1 Overview

This chapter provides the method, results, and discussion of the first experiment that was conducted, which aimed at a cross-linguistic replication of the findings of Maglio *et al.* (1999) in an attempt to fill a gap in the literature which exists based on the fact that nearly all previous studies of epistemic action have been applied to tasks of a spatial nature. Although the study by Maglio *et al.* (1999) was touched upon in Chapters 1 and 2, a fuller description of this study is therefore required here, as the method followed for the current experiment closely followed the method used by Maglio *et al.*, and as a number of predictions can be made on the basis of that piece of research, in conjunction with what the model described in Chapter 2 would predict.

3.2 The Maglio *et al.* (1999) Experiment

In a mixed factorial design, participants were tested across two conditions: One in which physical manipulation of the tiles was allowed (the 'Hands' condition), in other words, the performance of epistemic actions was allowed; and a second condition in which physical manipulation of the tiles was not allowed (the 'No Hands' condition). As participants could not be tested in both conditions on the same set of seven letters, Maglio *et al.* used two letter sets as stimuli, with the sets chosen on the basis of a norming task which was meant to ensure that the mean number of words producible from both sets (i.e., the productiveness of the sets) was approximately equal.

Maglio *et al.* discovered that physical manipulation did in fact aid in the generation of words, and took this as support for the fact that performing epistemic actions in their task was thus beneficial. The results are slightly more complicated, however, in that despite the norming task which was supposed to ensure relatively equivalent productivity across both letter sets, an interaction between physical manipulation and letter sequence occurred such that manipulation helped more only for one of the two sets; for the other set, there was no significant difference between the two manipulation conditions.

This interaction was explained by appealing to the relative difficulty of producing words from the different sets, with the idea being that physical manipulation would aid more, the more difficult it is to produce words from a set of letters. Taking the average length of the words produced as an initial measure of difficulty, Maglio *et al.* discovered no effect of the physical manipulation conditions on word length, and concluded on the basis of this that word length is not related to difficulty. The authors then appealed to the productiveness of the two sets, and the average written and spoken frequency of the words produced from both sets, using these as a semantic measure of word-generation difficulty. They discovered not only that far fewer words (53 words) could be generated from the letter set for which the performance of epistemic actions helped than the set for which epistemic actions did not help (92 words), but also that the set for which physical manipulation assisted contained words which were far less frequent in both written and spoken English.

The frequency effects indicate that it is not simply difficulty, but rather difficulty relating to linguistic factors, that can interact with the performance of epistemic actions in an experimental situation such as that of Maglio *et al.* (1999).

3.3 The Present Experiment

The present experiment was a cross-linguistic replication and extension of the Maglio *et al.* (1999) experiment, which required one group of participants to perform the task in their first language, and a second group of participants to perform the task in their second language. The experiment was therefore subdivided into two parts, where Experiment 1.1 refers to when the task was performed in English, and Experiment 1.2 refers to when the task was performed in Afrikaans. Afrikaans was chosen as the second language for this experiment as the participants were to be drawn from the University of Cape Town, situated in the Western Cape province of

South Africa, the language of instruction of which is English, and the university thus attracts a large number of first-language English speakers. The vast majority of first language English speakers take Afrikaans as a second language throughout the duration of their schooling, and English and Afrikaans were therefore selected as the first and second languages that the task was to be performed in. Afrikaans is a language which is diverse in terms of region, dialect, and social class, and originates not only from Dutch but also has features of Malay, Portuguese, Khoekhoe, French, German, and English (Penn *et al.*, 2001).

On the basis of the results observed in the Maglio *et al.* (1999) study, as well as the model presented in Chapter 2, a number of hypotheses concerning the effects expected in the present experiment can be put forward:

Hypothesis 1: Performing physical manipulation will aid word production compared to not performing physical manipulation when the task is performed in English.

Hypothesis 2: As with the Maglio *et al.* (1999) experiment, since it is required that two letter sets be used, an interaction between physical manipulation and letter set may occur. If this effect does occur, it is likely that physical manipulation will aid production more for the set from which the words that can be produced are less frequent in both written and spoken English.

Hypothesis 3: Physical manipulation should also aid production when the task is performed in Afrikaans. Demonstrating that this does occur would indicate that the epistemic action effect is reliable, and that it can be applied to task domains that possess processing requirements additional to spatial task demands.

Hypothesis 4: As it is required that two letter sets be used, an interaction between physical manipulation and letter set may also occur when the task is performed in Afrikaans.

3.4 Method

3.4.1 Participants

Participants were 80 undergraduate psychology students from the University of Cape Town who participated for course credit through the Student Research Participation Programme at the University of Cape Town, a programme which requires that students participate in research in exchange for course credit. All reported normal or corrected-to-normal vision. In order to qualify for Experiment 1.1, the participant's home language needed to be English; in order to qualify for Experiment 1.2, the participant had to have taken and passed Afrikaans as a second language in Grade 12, which would have indicated that they were sufficiently proficient in the language to perform the task adequately. The preceding information was gathered from participant self-reports. No demographic statistics were collected, although the sample consisted of both men and women (with the majority of participants being female) of various ethnic groups, with the majority of participants being in their early twenties.

Although Mendelsohn and Covington (1972) discovered that the visual presence or absence of anagrams had little effect on the anagram solving performance of males, but that the absence of the stimulus reduced performance in females, no gender effects were expected for the present experiment as the stimuli were consistently present. No effect of ethnic group was expected as there is nothing in the literature to indicate that race influences anagram solution performance. Age was not expected to influence performance in the task as research by Furby (1977) has demonstrated that developmental level does not determine the anagram solution strategy used. Of the 80 participants, 70 spoke English as a first language, one spoke Afrikaans, one German, one Ndebele and one Xhosa. Six participants classified themselves as bilingual, with two speaking both Shona and English as first languages, two speaking Norwegian and English, and one speaking Spanish and English. One participant classified themselves as speaking both of the task languages as first languages.

The relative influence that possessing a third lexicon could have in the present study cannot be conclusively predicted, as third language acquisition is complex because of a number of factors associated with it and its possible interactions (Cenoz, 2001). However, a recent study by Tremblay (2006) discovered that although a second language may intrude into a third language, the reverse does not seem to be the case. Considering that for the participants who spoke a language other than English as a first language, and who took and passed Afrikaans in Grade 12, that Afrikaans would be their third language, it can therefore be assumed on the basis of the study by Tremblay that any interference effects created between English and Afrikaans would therefore closely approximate the interference effects between English as an L1 and Afrikaans as an L2, as it was noted in Chapter 2 that interference is always usually greater from an L1 to an L2 rather than vice versa. Furthermore, Costa and Santesteban (2004) discovered that asymmetrical switching costs are not present between L1 and a third language, which indicates that interference from L1 into these participants' third language would most likely not occur.

3.4.2 Experimental Design

A 2 (*letter manipulation* – 'Hands' versus 'No Hands'*)* X 2 (*letter set* – set 1 versus set 2*)* mixed factorial design was employed, with *letter manipulation* being the within-subjects factor and *letter set* the between-subjects factor

The independent variables included *letter manipulation* and *letter set.* 'Epistemic action' is a theoretical construct which is required to be operationalised for experimental purposes, and the operationalisation of which may vary from experiment to experiment, depending on the task domain within which the construct is investigated. For the purposes of this study, the construct was operationalised via *letter manipulation,* and comprised two conditions: the 'Hands' condition (i.e., the performance of epistemic actions), in which participants were allowed to use their hands to physically move the tiles around; and the 'No Hands' condition (i.e., the non-performance of epistemic actions), in which participants could not move the tiles around. *Letter set* refers simply to the letter sets used as stimuli for the test trials.

The dependent variables for the main analysis included *number of words produced* and *average word length. Number of words produced* refers to the average number of words produced by the participants during each of the test trials. *Average word length* refers to the overall average number of letters that each word made by each participant, in each test trial, was composed of.

In order to test the hypothesis that letter manipulation may aid production for the set from which less frequent words were produced, it was planned that an additional analysis using *letter manipulation* and *letter set* as independent variables, and *Kucera and Francis written frequency* and *Brown verbal frequency* as dependent variables, would be performed.

According to Wilson (1988), the *Kucera and Francis written frequency* refers to a words written frequency of occurrence as given in the norms of Kucera and Francis (1967). For this study, the raw frequency values were used, and the average written frequency of the words produced by participants was obtained from the online MRC Psycholinguistic Database: Machine Readable Dictionary, Version 2 (see Wilson, 1988, for an explanation of the database and its construction) at http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm. The maximum frequency in the file is 69 971, and the minimum is 0. The mean and standard deviation is not reported on the database.

Brown verbal frequency refers to the frequency count of spoken English obtained from the London-Lund Corpus of English Conversation by Brown (1984) (Wilson, 1988). As with the written frequency, the raw average verbal frequency of the words produced by participants was obtained from the online MRC Psycholinguistic Database. The range of entries is 0 – 6833, with a mean of 35 and a standard deviation of 252.

Although verbal frequency data for Afrikaans exists in the form of Van Rooy (2002), a copy of this manual unfortunately could not be obtained, and Afrikaans frequency data could therefore not be included in the analysis.

3.4.3 Apparatus

The apparatus used for these experiments consisted of seven tiles from the board-game Scrabble. As the participants could not perform both the 'Hands' and 'No

Hands' conditions on the same letter set, two sets of letters were required that contained approximately equivalent amounts of productiveness, where productiveness was measured as being the average number of words produced from each letter set, not only across the sets themselves, but also across both task languages. Maglio *et al.* (1999) report normative data regarding the mean number of English words that are able to be produced from six randomly generated letter sets. Normative data for the mean number of Afrikaans words that could be produced from those six sets was thus required, and as such a second norming task was performed.

Selection of letter sets:

For the norming task, seven undergraduate students from the University of Cape Town were recruited by placing posters advertising the study around the university campus. The posters asked for participation in a word generation task experiment for payment of 50 South African Rand, and explicitly stated that speaking Afrikaans as a first language was a prerequisite for participation in the study.

Each participant was shown each of the six letter sets used in Maglio *et al.'s* norming task, and were instructed that they would have five minutes in which to write down as many Afrikaans words as they could produce by rearranging the letters in each sequence. A one-way analysis of variance (ANOVA) indicated a significant difference (shown in Figure 2) in the number of words made from each of the six letter sets, $F(5, 36) = 2.58$, $p = 0.043$, $\eta^2 = 0.26$. Inspection of the Fisher Least Significant Difference (LSD) matrix revealed significant differences between the number of words made for letter set 5 and all other sets. Set 5 was thus disregarded as a possible stimulus.

In order to further reduce the number of possible stimuli, ±99% confidence intervals for each letter sequence were calculated from the data produced from the Afrikaans norming task. This data, as well as the means from this and the Maglio *et al.* norming task, are reported in Table 1. As the mean number of English words made from set 6 did not fall within the upper limit of the confidence interval from the Afrikaans data, this set was disregarded as a possible stimulus. Letter set 2 was excluded as a possible stimulus as inspection of the means revealed too great a difference between the average numbers of words produced for English and Afrikaans.

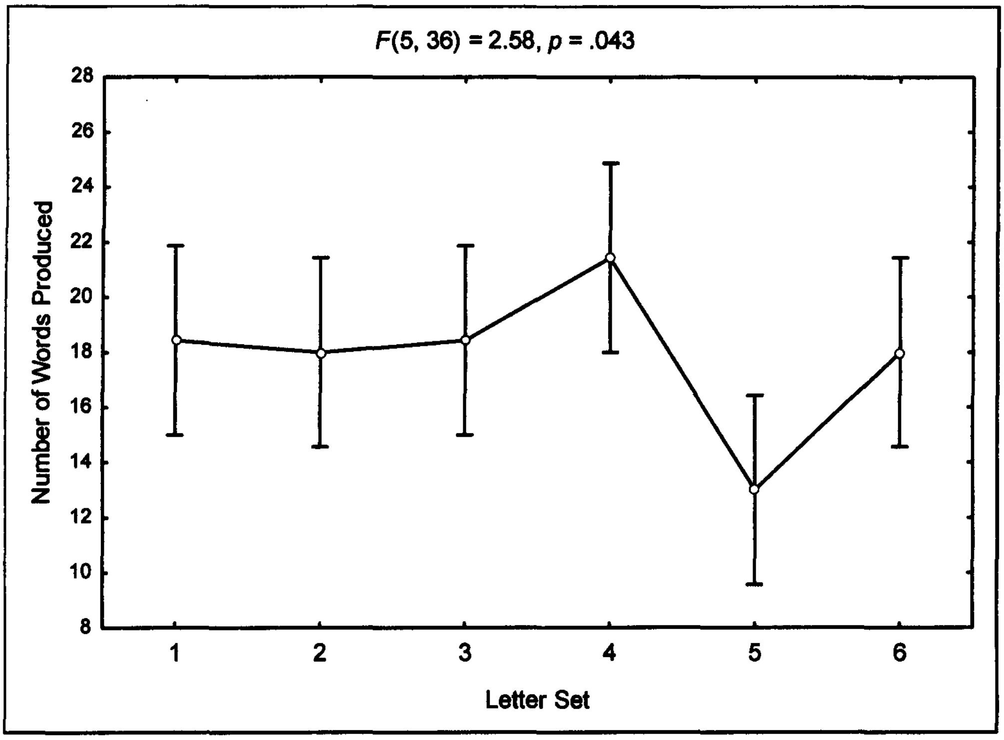

Figure 2. Means plot of the effect of *letter set* on number of words produced for the norming task.

A further one-way ANOVA between sets 1, 3, and 4 was non-significant, $F(2, 18) = 0.79, p = 0.465$. From these three remaining sets, 1 and 3 were chosen as the final stimuli, as inspection of the means indicates that exactly the equivalent number of words in Afrikaans can be produced from these two sets, and no significant difference between the mean number of English words that are able to be made from these two sets was reported in Maglio *et al.* (1999). From the remaining four letter sets, sets 4 and 6 were randomly selected as practice stimuli, with Set 5 excluded from selection due to the significant difference in the number of words made from this set and all others reported above.

3.4.4 Procedure

Each experimental session was run in one of three dedicated rooms, lasted approximately 45 minutes, and comprised between one and a maximum of five participants run simultaneously.

Table 1.
Mean Number of Words Produced and ±99% Confidence Intervals Per Set

	Number of Words		Confidence Intervals	
Letter Set	English	Afrikaans	-99%	99%
1. NDRBEOE	19.88	18.43	10.55	26.31
2. ESIFLCE	12.06	18	11.43	24.57
3. EMTGPEA	22.25	18.43	12.07	24.79
4. RDLOSNA	20.81	21.43	14.2	28.66
5. IRCDEOE	16.19	13	9.04	16.96
6. LNAOIET	26.07	18	13.21	22.79

Note. The ±99% confidence intervals are for the Afrikaans norming data only.

Participants were instructed that they would have five minutes to produce as many English/Afrikaans words (depending on the group to which they were assigned) as possible from the letters given that are at least two letters long. They were told that they could not form proper nouns, abbreviations, or acronyms, and that each word made did not have to use every letter in the set such that the words could be anywhere between two and seven letters in length.

The task began with a practice trial using one of the two practice stimuli, counterbalanced across participants. Participants assigned to the 'Hands' condition were instructed that they could physically manipulate the tiles to assist with word formation, whilst participants assigned to the 'No Hands' condition were explicitly instructed that they could not physically manipulate the tiles, and were visually monitored by the experimenter to ensure that they did not in fact manipulate the letter sets. Practice proceeded for five minutes, after which the participants performed one of two distractor tasks for five minutes.

As both visual and verbal working memory are involved in a task that requires participants to generate verbal data from visual stimuli (Segalowitz & Frenkial-Fishman, 2005), the distractors comprised either a task with visuospatial loading (copying the Rey-Oesterith Complex Figure) or verbal loading (the Babcock Story Recall task) (Lezak, Howieson, & Loring, 2004) (see Appendix A for a description of the distractors). The order of performance of the distractor tasks was counterbalanced across participants. For example, for every one participant who performed the Rey Complex Figure, then the Babcock Story Recall, then the Rey

Complex Figure, there was a participant who performed the opposite pattern of distractor tasks, for example, Babcock Story Recall, then Rey Complex Figure, then Babcock Story Recall again.

After the first distractor, each participant performed the first test trial in the same condition as the practice trial (e.g. 'Hands' practice followed by 'Hands' test) before performing the other distractor task, and then onto the other *letter manipulation* condition in the same manner as before, in other words practice followed by distractor followed by test. The procedure can be displayed as follows:

Practice1 → Distractor 1 → Test trial 1 → Distractor 2 → Practice 2 → Distractor 1 → Test trial 2

In each instance, the sequence of letters for each set was laid out in exactly the same order for each participant. Participants were required to write down the words that they generated on a pre-printed sheet of lined paper. All English words created were checked for legality using the online version of the Oxford English Dictionary (www.oed.com), and all Afrikaans words created were checked for legality using the Webster's online Afrikaans-English dictionary (www.websters-dictionary-online.org/definition/Afrikaans-english).

3.5 Results

3.5.1 Experiment 1.1

This experiment aimed to replicate, the original findings reported in Maglio *et al.* (1999). It further aimed to extend the original findings by determining whether or not performing epistemic actions, as well as the particular letter sets used as stimuli, and the interaction between the two, had an effect on the average verbal and/or written frequency of the words produced by participants. Inspection of the descriptive statistics of participants' home languages revealed that five participants who took part in this experiment did not speak English as a first language. These five cases were thus excluded from the analysis.

3.5.1.1 Effect of epistemic actions and letter set on word production and length

To test whether or not performing epistemic actions has an effect not only the number of words made from a particular letter set, but also the average size of those words, a 2 (*letter manipulation* – 'Hands versus 'No Hands') X 2 (*letter set* – set 1 versus set 2) factorial ANOVA was conducted.

Number of words produced:

Descriptive statistics for this analysis, and a summary of the results, are given in Tables 2 and 3 below. The results reveal no significant main effect for *letter manipulation*, $F(1, 66) = 0.22, p = 0.640$, indicating that performing epistemic actions did not significantly affect the number of words made.

Table 2.

Descriptive Statistics for Number of Words Produced

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. NDRBEOE	20	17.95	3.41	15	20.20	5.75
2. EMTGPEA	15	23.53	4.07	20	20.30	4.13

Table 3.

Analysis of Variance for Number of Words Produced

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	0.22	<.01	.640
Letter Set (LS)	1	7.37**	.09	.009
LM X LS	1	6.84*	.09	.011
Error	66	(18.78)		

Note. Values in parantheses represent mean square errors.
$^*p < .05$. $^{**}p < .01$.

However, a significant main effect for *letter set* was observed, $F(1, 66) = 7.37$, $p = 0.009$, indicating that the particular letter set used did significantly influence the number of words made, with more words made from letter set 2 ($M = 21.67$) than letter set 1 ($M = 18.91$), although the effect size was modest, $\eta^2 = 0.09$. A significant interaction effect, displayed in Figure 3, was also revealed, $F(1, 66) = 6.86$, $p = 0.011$, $\eta^2 = 0.09$, signifying that letter manipulation interacted with the particular letter set used.

The interaction effect prompted a series of post-hoc analyses. These analyses included an investigation of whether or not the difference between the 'Hands' and 'No Hands' conditions was significant for both letter sets 1 and 2, as well as whether or not the difference between letter sets 1 and 2 was significant for the 'Hands' condition. All these analyses were conducted using one-way ANOVAs. For these analyses, the F-values were recalculated by dividing the mean square effect from the one-way ANOVA by the mean square error from the factorial ANOVA. The p-values were recalculated with the probability calculator function of the STATISTICA statistical analysis software, using the new F-value, and the degrees of freedom effect from the one-way ANOVA and the degrees of freedom error from the factorial ANOVA, in order to increase the power of these analyses.

Inspection of the cell mean plot (Figure 3) indicated that it was unlikely that a significant difference between letter sets 1 and 2 for the 'No Hands' condition existed, thus this analysis was not conducted. For letter set 1, no significant difference between the 'Hands' and 'No Hands' conditions was observed, $F(1, 66) = 2.31$, $p = 0.157$.

However, the opposite effect was revealed for letter set 2, with more words made in the 'Hands' ($M = 23.53$) than the 'No Hands' condition ($M = 20.30$). This difference was statistically significant, $F(1, 66) = 4.77$, $p = 0.032$, $\eta^2 = 0.14$.

The results of the analysis using *letter set* as the independent variable, and including the 'Hands' condition only, yielded a significant difference between letter sets 1 and 2, $F(1, 66) = 14.23$, $p < 0.001$, $\eta^2 = 0.37$, with more words being produced from letter set 2 ($M = 23.35$) than letter set 1 ($M = 17.95$).

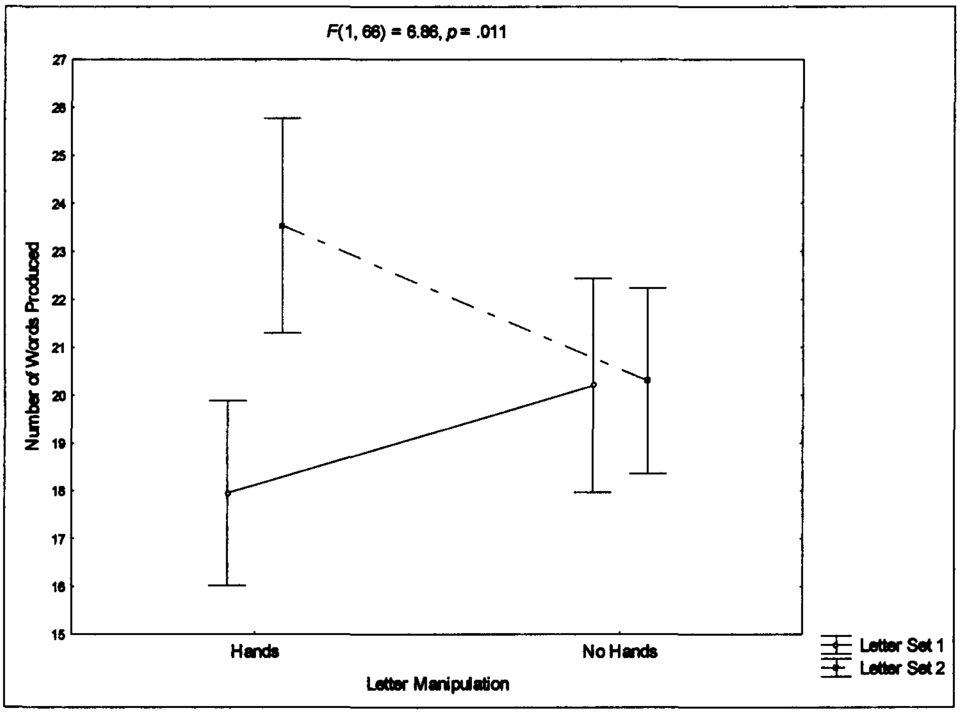

Figure 3. Means plot of the interaction between *letter manipulation* and *letter set* on number of words produced.

Average word length:

Descriptive statistics for this analysis, and a summary of the results, are given in Tables 4 and 5 below. As with number of words produced, no significant main effect for *letter manipulation* was evident, $F(1, 66) = 0.12$, $p = 0.732$, whilst a significant main effect for *letter set* was apparent, $F(1, 66) = 18.35$, $p < 0.001$, $\eta^2 = 0.22$.

Table 4.

Descriptive Statistics for Average Word Length

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. NDRBEOE	20	3.54	0.17	15	3.53	0.19
2. EMTGPEA	15	3.36	0.12	20	3.40	0.09

However, the opposite pattern to the previous analysis was observed; here, the mean for letter set 1 ($M = 3.53$) is greater than the mean for letter set 2 ($M = 3.38$), although the difference is slight (a mean difference of 0.15 letters).

Table 5.
Analysis of Variance for Average Word Length

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	0.12	<.01	.732
Letter Set (LS)	1	18.35**	.22	<.001
LM X LS	1	0.51	.01	.476
Error	66	(0.02)		

Note. Values in parantheses represent mean square errors.
$^*p < .05$. $^{**}p < .01$.

Unlike the previous analysis, no significant interaction effect was observed, $F(1, 66) = 0.51, p = 0.476$.

3.5.1.2 Effect of epistemic actions and letter set on the average verbal and written frequency of the words produced

This analysis was conducted to test the hypothesis that the interaction effect between *letter set* and *letter manipulation* occurs as a result of the fact that the words that can be produced from one letter set are more frequent in both spoken and written English. More specifically, it is hypothesised that there will be a significant difference between the two letter sets for both the average Brown Verbal and Kucera and Francis Written frequency, and that the average of each frequency will be lower for the letter set for which performing epistemic actions had an effect, in other words letter set 2. Descriptive statistics for this analysis are reported in Tables 6 and 8, and a summary of the analysis is reported in Tables 7 and 9.

Table 6.
Descriptive Statistics for Average Brown Verbal Frequency

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. NDRBEOE	20	268.64	198.99	15	235.38	146.688
2. EMTGPEA	15	73.83	37.02	20	64.28	35.23

Table 7.
Analysis of Variance for Average Brown Verbal Frequency

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	0.47	.01	.494
Letter Set (LS)	1	34.54**	.34	<.001
LM X LS	1	0.15	.00	.705
Error	66	(16 612)		

Note. Values in parantheses represent mean square errors.
*$p < .05$. **$p < .01$.

To test whether or not performing epistemic actions, as well as the particular letter sets used as stimuli had an effect on the average verbal and written frequency of the words produced, a 2 (*letter manipulation* – 'Hands' versus 'No Hands') X 2 (*letter set* – set 1 versus set 2) factorial ANOVA was conducted. The results (summarised in Tables 8 and 9) indicate that this is in fact the case, with a significant main effect for *letter set* for both the Brown Verbal Frequency, $F(1, 68) = 37.21$, $p < 0.001$, and the Kucera and Francis Written Frequency, $F(1, 68) = 34.68$, $p < 0.001$, with the effect sizes for both written, $\eta^2 = 0.34$, as well as spoken, $\eta^2 = 0.33$ frequency being noticeably larger than those for both average number of words produced and average word size.

Table 8.
Descriptive Statistics for Average Kucera and Francis Written Frequency

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. NDRBEOE	20	543.88	396.16	15	603.46	396.97
2. EMTGPEA	15	184.94	123.34	20	144.85	114.67

No significant main effect for *letter manipulation* was observed for either the Brown Verbal Frequency, $F(1, 66) = 0.47$, $p = 0.494$, or the Kucera and Francis Written Frequency, $F(1, 66) = 0.02$, $p = 0.891$.

Table 9.
Analysis of Variance for Average Kucera and Francis Written Frequency

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	0.02	<.01	.891
Letter Set (LS)	1	33.56**	.33	<.001
LM X LS	1	0.49	.01	.483
Error	66	(85 620)		

Note. Values in parantheses represent mean square errors.
$^{*}p < .05$. $^{**}p < .01$.

Likewise, no significant interaction effect for either verbal frequency, $F(1, 66) = 0.15$, $p = 0.705$ or written frequency, $F(1, 66) = 0.49$, $p = 0.483$ was apparent.

Inspection of the means for each dependent variable indicates that for the Brown Verbal Frequency, words that are more frequent in spoken English were made from letter set 1 ($M = 254.39$) than letter set 2 ($M = 68.37$). Similarly, for the Kucera and Francis Written Frequency, words that are more frequent in written English were made from letter set 1 ($M = 569.42$) than letter set 2 ($M = 162.03$). The results of this analysis can thus be interpreted as indicating that the words implicitly contained in set 2 are far less frequent in both spoken and written English than the words implicitly contained in set 1.

3.5.2 Experiment 1.2

This experiment was a further extension of the original Maglio *et al.* (1999) experiment, with the aim of discovering what effect the letter manipulation has when the task is performed in the participants' second language as opposed to their first language. As the requirement for inclusion in this experiment was to have taken and passed Afrikaans as a second language at Grade 12 level, the five cases that were excluded from the analysis for Experiment 1.1 were now included in this analysis.

3.5.2.1 Effect of epistemic actions and letter set on word production and length

As with Experiment 1.1, a 2 (*letter manipulation* – 'Hands' versus 'No Hands') X 2 (*letter set* – set 1 versus set 2) factorial ANOVA was performed.

Number of words produced:

Descriptive statistics, and a summary of the results, are given in Tables 10 and 11 below. Of note is that although the average number of words produced by participants in this experiment is lower than in Experiment 1.1, the average size of the words is approximately the same (see Table 4 above). As with Experiment 1.1, no significant main effect for *letter manipulation* was discovered, $F(1, 76) = 1.02$, $p = 0.316$, although a significant main effect for *letter set* was evident, $F(1, 76) = 7.65$, $p = 0.007$, $\eta^2 = 0.09$. However, closer inspection of the results indicates that letter set 1 ($M = 8.13$) exerted more of an influence on the number of words formed than letter set 2 ($M = 6.55$), whereas the opposite was the case in Experiment 1.1. As with the previous experiment, a significant interaction effect between *letter manipulation* and *letter set*, shown in Figure 4, was observed, $F(1, 76) = 5.01, p = 0.028, \eta^2 = 0.06$.

Table 10.

Descriptive Statistics for Number of Words Produced

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. NDRBEOE	20	9.05	2.58	20	7.20	3.12
2. EMTGPEA	20	6.20	2.48	20	6.90	1.83

Three post-hoc analyses, all performed using one-way ANOVAs, were conducted in order to examine the interaction effect observed in the results of the factorial ANOVA. The same procedure for recalculating the *p*-values was used for these analyses as was used for Experiment 1.1. The first two analyses were an investigation of whether or not the difference between the 'Hands' and 'No Hands' conditions was significant for both letter sets 1 and 2.

Table 11.
Analysis of Variance for Number of Words Produced

Source	*df*	*F*	η^2	*p*
Letter manipulation (LM)	1	1.02	<.01	.316
Letter Set (LS)	1	7.65**	.09	.007
LM X LS	1	5.01*	.06	.028
Error	76	(6.49)		

Note. Values in parantheses represent mean square errors.
*$p < .05$. **$p < .01$.

The third and final analysis was an investigation of whether or not the difference between letter sets 1 and 2 was significant for the 'Hands' condition. For letter set 1, as expected, a significant difference between the 'Hands' and 'No Hands' conditions was observed, $F(1, 76) = 5.27, p = 0.024, \eta^2 = 0.10$, with more words being made in the 'Hands' ($M = 9.05$) than the 'No Hands' condition ($M = 7.20$).

For letter set 2, no significant difference between the 'Hands' and 'No Hands' conditions was observed, $F(1, 76) = 0.76$, $p = 0.317$. The one-way ANOVA performed using *letter set* as the predictor, and number of words as the dependent variable, for the 'Hands' condition only, revealed a significant difference between the two letter sets, $F(1, 76) = 12.52, p = 0.001, \eta^2 = 0.25$, with more words being made from letter set 1 ($M = 9.05$) than letter set 2 ($M = 6.20$).

Average word length:

Descriptive statistics, and a summary of the results of this analysis, are given in Tables 12 and 13 below.

Table 12.
Descriptive Statistics for Average Word Length

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. NDRBEOE	20	3.55	0.34	20	3.61	0.27
2. EMTGPEA	20	2.9	0.18	20	2.88	0.19

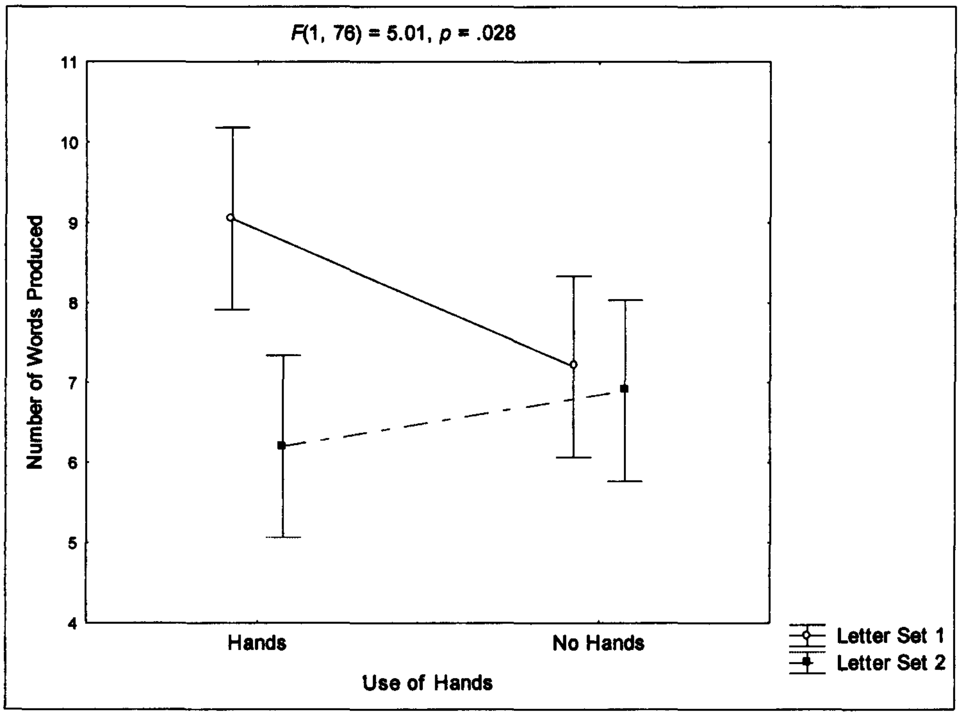

Figure 4. Means plot of the interaction between *letter manipulation* and *letter set* on number of words produced.

Table 13.
Analysis of Variance for Average Word Length

Source	*df*	*F*	η^2	*p*
Letter manipulation (LM)	1	0.12	.00	.734
Letter Set (LS)	1	147.52**	.66	<.001
LM X LS	1	0.52	.00	.473
Error	76	(0.06)		

Note. Values in parantheses represent mean square errors.
**p* < .05. ***p* < .01.

As with Experiment 1.1, no significant main effect for *letter manipulation*, $F(1, 76) = 0.12, p = 0.734$, or significant interaction effect, $F(1, 76) = 0.52, p = 0.472$ was detected. Again, a significant main effect for *letter set* was observed, $F(1, 76) = 147.52, p < 0.001, \eta^2 = 0.66$, with letter set 1 ($M = 3.58$) resulting in words of a greater average length being produced than letter set 2 (M = 2.89), as was the case with the number of words produced.

3.6 Discussion

3.6.1 Experiment 1.1

The results of Experiment 1.1 essentially demonstrate the replication of the epistemic action effect observed in Maglio *et al.* (1999) in terms of number of words produced, but with some important deviations from their results. No significant main effect for letter manipulation was obtained, whilst a significant main effect for letter set was obtained, the opposite pattern of results to those observed by Maglio *et al.* (1999). As with their study, a significant interaction effect was obtained in the present study, although it is extremely small. Unfortunately a comparison with the effect size obtained in the Maglio *et al.* study cannot be made, as effect sizes were not reported in this study.

The interaction effect was predicted based on the results of the Maglio *et al.* study, which discovered that physical manipulation aided word production only for one of the two letter sets. This was also the case in the present study, and moreover, it was with the same letter set that was used in the Maglio *et al.* study ('EMTGPEA'), despite the fact that the norming task was supposed to ensure that an equivalent amount of words were produced from each of the two letter sets. As with the Maglio *et al.* study, the results of the present analysis also indicated that for the other letter set ('NDRBEOE'), physically moving the tiles had a marginal and even opposite effect, with slightly more words (approximately two) being made in the 'No Hands' compared to the 'Hands' condition, although this difference was not statistically significant in terms of the post-hoc analyses conducted here.

As predicted on the basis of the results obtained by Maglio *et al.*, the interaction effect can be explained in terms of the relative frequency of the words produced from each letter set. For the letter set in the Maglio *et al.* study for which physical manipulation helped, the words contained in this set were far less frequent than the words contained in the set for which manipulation did not help. This result was confirmed in the present analysis, with the results indicating that for letter set 2 ('EMTGPEA'), the words produced were far less frequent in both written and spoken English than the words produced from letter set 1 ('NDRBEOE').

Maglio *et al.* (1999) take the frequency effects as a semantic measure of the word-generation difficulty of the letter sets, and explain the interaction in terms of the fact that it is therefore more difficult to generate words from the set which contains lower frequency words. Frequency effects are also predicted in terms of the model presented in Chapter 2, in which words of a lower frequency have lower average resting levels of activation, and thus require more excitation to push them above the recognition threshold. In terms of the model, physically manipulating the tiles could possibly result in the neighbourhood density of the originally presented letter string changing, such that the recognition of words would be facilitated via an increase in the summed lexical activity, such that the time taken to settle on a target word is reduced.

The fact that the opposite result occurred, that is, that physical manipulation did not have an effect and that the trend was in the opposite direction, can also be predicted on the basis of the model described in Chapter 2. In terms of the model, if the words producible from a letter set are of a high frequency, they are already at a high average resting level of activation, and do not require any extra excitation to push them above the recognition threshold; physical manipulation is not needed, as the words are already easy to 'find' in the letter set, and so pop-out more quickly and easily. In this case, the opposite effect for physical manipulation may occur. For example, given an arrangement of letters such as 'C B E H A,' the solution to which is *beach*, the letters may be arranged into an arrangement such as 'E A H C B,' in which it is easier to recognise the word. In the first case, the time to settle on the target can be given by t, whereas in the second case the time to settle on the target is quicker, say $t - a$. However, the opposite effect may occur such that the arrangement 'E A H C B' exists first, and physical manipulation results in 'C B E H A.' In this case, the time taken to settle on the target is *longer*, say $t + a$. This is a case of *divergence*, rather than convergence, by manipulation of orthographic neighbourhood. Further support for this hypothesis comes from the finding in the post-hoc analyses that no difference between the amount of words produced from the two letter sets existed for the 'No Hands' condition, but for the 'Hands' condition, a significant difference was obtained such that more words were produced in this condition from letter set 2 relative to letter set

1 (see Figure 3 in Section 3.5.1.1 above). In other words, in the case of the 'No Hands' condition, the time taken to settle on any particular word is simply t, for both letter sets. For the 'Hands' condition, the time taken to settle on any particular word is $t - a$ for letter set 2 (from which words of a lower frequency are producible), whereas in the case of letter set 1, the time taken to settle on any particular word would be given by $t + a$ (from which words of a higher frequency are producible).

Another possible explanation of the interaction effect can also be given in terms of the fact that the model incorporates theories which predict that search is likely to begin by initial letter. English words starting with a vowel make more difficult anagrams as most words start with a consonant, and so participants are not likely to explore vowel-beginning words first (Gilhooly & Johnson, 1978). Similarly, a recent study by Novick and Sherman (2007) demonstrated in a regression analysis that first letter predicts anagram solution time such that solutions are obtained quicker when the word begins with a consonant rather than a vowel. In terms of the two letter sets used as stimuli, one ('NDRBEOE') began with a consonant, whilst the other ('EMTGPEA') began with a vowel.

In terms of the model presented in Chapter 2, physical manipulation can aid word production by allowing an individual to physically manipulate and fix the first letter of the letter string, thus placing it out of memory and into the visual store. Since a consonant was already fixed in the first position in the letter set 'NDRBEOE,' physical manipulation in this way would not be required and thus no significant effect for manipulation would be expected. In terms of the letter set 'EMTGPEA,' physically fixing a consonant in the first position would aid in production more, and this is indicated by the finding of a significant effect for manipulation such that manipulation aids production compared to non-manipulation. An examination of the letter sets used by Maglio *et al.* (1999) also indicates that the letter set used in that study for which no effect of manipulation was obtained also began with a consonant ('RDLOSNA'), which provides more evidence for this interpretation.

A second pertinent finding in the current analysis concerns the discovery of a significant main effect of letter set on both the number of words produced and the average length of the words produced. Taken together, these results suggest that the letter sets exert an influence in the task that is independent of physical manipulation. Physical manipulation, on the other hand, seems to be tied to the particular letter set used, in that no significant main effect for this factor was evident but a significant interaction effect between manipulation and letter set was obtained. This suggests that the epistemic action effect may be ephemeral, being linked to the particular letter set used. Another possibility is that the epistemic action effect simply exerts a random influence, and this possibility is supported by the small effect sizes. However, the first possibility is more likely as an interaction effect was detected in both the study of Maglio *et al.* (1999) and in the present study. Thus, although its effect is small, the effect does seem to be reasonably reliable.

Concerning the main effect of letter set on the average length of the words produced, this effect is actually in the opposite direction to that predicted by the fact that shorter words are usually of a higher frequency than longer words (Vitevitch & Rodriguez, 2005), in that in this experiment it was discovered that the words made from letter set 1 were longer but of a higher frequency than the words made from letter set 2. However, this effect is predicted by the model presented in Chapter 2 when the interaction effect between letter set and physical manipulation is taken into account. In terms of this model, physical manipulation aids in the generation of more words from the less frequent set by allowing a convergence on the target via a manipulation of the orthographic neighbourhood, and a correlation between length and neighbourhood size also exists such that longer words in English tend to have no or few neighbours, while shorter words have many neighbours (Andrews, 1997). Thus, more words of a shorter length would have been produced from the letter set from which words of a lower frequency are produced as a result of the fact that physical manipulation aids production more for the less frequent set. In this sense, the contradiction in results can possibly be explained in terms of the performance of epistemic actions, and the interaction effect between letter manipulation and letter set.

3.6.2 Experiment 1.2

The first significant finding in this analysis concerns the fact that the pattern of results obtained for the number of words produced were virtually identical to the pattern of results from the analysis of the English data, that is, that no significant main effect for letter manipulation was discovered, whilst a significant main effect for letter set and a significant interaction effect was obtained. This testifies further to the reliability of the epistemic action effect, as the results from this effect are thus replicable across two different languages.

As was the case with the English results, post-hoc analysis of the interaction effect revealed that physical manipulation aided word generation from only one of the two letter sets, with no difference between the two manipulation conditions discovered for the other letter set. This result could be explained by appealing to the relative frequency of the words produced from each of the two letter sets, in other words, that the words produced from letter set 1 were less frequent in Afrikaans than the words produced from set 2. Considering that the findings for the English condition can be explained in terms of frequency effects, it is not unreasonable to suppose that the Afrikaans findings are also due to frequency effects, especially considering the high overlap in findings between the English and Afrikaans data. For example, in addition to the same general pattern of results emerging in this analysis compared to the analysis of the English data, a significant difference between the two letter sets for the 'Hands' condition was discovered, with no significant difference between the two letter sets for the 'No Hands' condition discovered, as was the case with the English results. If it is the case that the explanation for this lies in the frequency effects predicted by the model, then the same explanation given for this result in the discussion of the English data applies here. This explanation cannot be directly tested as no frequency data for the Afrikaans words was available, and therefore remains speculative.

What is of particular interest is that the letter set for which the use of hands aided word generation is the seemingly opposite set for which the use of hands aided generation for English – for English, performing epistemic actions aided generation for letter set 2 but not set 1; for Afrikaans, performing epistemic actions aided generation for letter set 1 but not set 2. This may be co-incidence, in terms of the fact that the letter set effect may be linked to frequency and productiveness. If this is the case and set 1 allows more words to be produced in English and fewer in Afrikaans, and vice versa for letter set 2, then this could simply be the same effect, and it just so happens that there are only two letter sets and so it appears to be an opposite effect. However, the norming task was supposed to ensure that an equivalent amount of words were producible from both letter sets in both Afrikaans and English. In addition, the epistemic action effect only seems to occur via the interaction between letter manipulation and letter set, and an explanation in terms of why this occurs must therefore be sought.

Another possible explanation, which can be derived from the model presented in Chapter 2, concerns the concept of 'reactive inhibition' across the two languages of the bilingual developed by Green (1998, cited in Costa & Santesteban, 2004). In terms of the 'reactive inhibition' concept, when accessing an L2, the magnitude of inhibition applied to L1 must be greater than vice versa in order for successful selection of L2 lexical items to occur. In terms of the interactive activation model which is incorporated into the model presented in Chapter 2, frequency effects are predicted on the basis that low frequency English words have lower baseline resting levels of activation, whereas higher frequency words have higher baseline resting levels of activation. When the concept of reactive inhibition is taken into account, this would mean that more inhibition would need to be applied to high frequency L1 words than to low frequency L1 words when the experimental task is performed in a second language. Considering that the words produced from letter set 1 when the task was performed in English were of a higher frequency than the words produced from letter set 2 in English, more reactive inhibition would need to be applied in the former case compared to the latter. In the former case, the selection of Afrikaans words may possibly have been more difficult, whereas in the latter case, the selection of Afrikaans words would possibly have been easier.

It is in the former case involving letter set 1, that is, when selection and hence production of words is more difficult in Afrikaans, that physical manipulation would aid more, and this is indicated by the finding in the post-hoc analyses of a significant difference between the two manipulation conditions for letter set 1 such that more words were produced in the 'Hands' condition. However, this conclusion remains rather speculative as no tests designed to measure the relative amount of reactive inhibition were applied in the present experiment, but given the fact that a reversed effect was not expected on the basis of the norming task, it remains a possibility nonetheless.

The final significant finding of the second part of Experiment 1 concerns the main effect for letter set on the average length of the words produced. Whereas for English less words of a longer length were produced from letter set 1, and more words of a shorter length were produced from letter set 2, for Afrikaans, more words of a greater average length were produced from letter set 1, whereas less words of a shorter average length were produced from letter set 2. Again, this could be pure co-incidence, as no feature of the letter sets was explicitly manipulated. However, since a significant interaction effect between letter set and manipulation was obtained, and given that the letter sets used in this experiment were the same for both the English and Afrikaans conditions, an explanation in terms of the fact that a possibly reciprocal influence between the two languages and the two letter sets exists cannot be excluded.

The model presented in Chapter 2, which incorporates aspects of the bilingual interactive activation model of van Heuven *et al.* (1998) can provide a possible explanation for the length effect obtained. In terms of the model presented in Chapter 2, and the findings regarding the analysis of the English data, convergence by manipulation of orthographic neighbourhood was more likely to occur for letter set 2 than for letter set 1 in English, which possibly explains the pattern of results observed in Experiment 1.1. However, increasing the number of English neighbours would activate the English language node which would in turn inhibit the Afrikaans language node. Additionally, due to reduced Afrikaans frequencies English words will be activated earlier in the recognition process, and this would in turn lead to an extra inhibitory effect from the English to the Afrikaans lexicon.

This extra inhibitory effect may result in a reduced efficiency of L2 lexical access, meaning that additional processing resources would be required to access the L2 lexicon in this case. Since longer words require more operations to compose (Maglio *et al.*, 1999), and therefore more cognitive resources for their composition, only shorter words are able to be produced. Since convergence by manipulation of orthographic neighbourhood is less likely to occur for letter set 1, efficiency of access to the Afrikaans lexicon would be compromised less in this case, which would result in processing resources being freed up to aid in the application of operators. This would result in words of a longer average length being produced. The reason why this effect is not reversed (i.e., that Afrikaans neighbours compromise efficiency of English lexical access) is that between-language neighbourhood effects are always greater from L1 into L2 than the reverse (van Heuven *et al.*, 1998). In fact, the effect of letter set on average word length was far greater for Afrikaans ($\eta^2 = 0.66$) than for English ($\eta^2 = 0.22$).

3.7 Conclusion

The results of this experiment, a replication and extension of that of Maglio *et al.* (1999), therefore demonstrate that certain aspects of the original experiment can be replicated whilst others cannot. For the English results, the main effect of letter manipulation on the number of words produced could not be replicated, although the interaction effect could. The finding in Maglio *et al.* (1999) that manipulation did not affect word length was replicated in the present experiment, although the finding of a significant main effect of letter set on the average length of the words produced was not predicted on the basis of the results reported in Maglio *et al.* (1999).

The results of the analysis of the Afrikaans data indicate that the epistemic action effect is to some extent reliable, as a highly similar pattern of results was obtained in this analysis, such that no significant main effect for letter manipulation on the number of words produced was found, but a significant main effect for letter set, and a significant interaction effect, was detected. The pattern of the interaction effect is interesting in that it appears to be the opposite pattern to that detected for the English analysis, and this may be an indication that cross-language interference effects are occurring in this task. As with the English results, no significant main effect of manipulation on average word length was found, although a significant main effect for letter set was evident.

The significant main effect of letter set that was discovered in both the English and Afrikaans analyses appears to indicate that the particular letter sets used as stimuli exert an influence on the results at least to some extent. In this regard, a follow-up study (Experiment 2) was conducted that aimed to manipulate the productiveness of the letter sets that were to be used as stimuli, in order to investigate whether letter manipulation has relatively more (or less) of an effect when the letter strings used as stimuli have relatively more (or less) productiveness. This experiment is described in the next chapter.

Chapter 4

Experiment 2

4.1 Overview

Having demonstrated in Experiment 1 the fact that word frequency can influence the extent to which epistemic actions aid word generation, and that the letter strings used as stimuli exert an influence that is independent of letter manipulation, the first aim of this experiment was to investigate the claim by Maglio *et al.* (1999) that the productiveness of the letter sets influences the extent to which epistemic actions aid word generation. In their experiment, Maglio *et al.* noted that the letter set for which epistemic actions aided word production contained fewer words that could be produced from it than the letter set for which epistemic actions did not aid word production. Taking the relative productiveness of the sets as a semantic measure of word-generation difficulty, they reasoned that epistemic actions aid generation more for the less productive set only, as it is therefore more difficult to create words from this set. This reasoning was post-hoc, however, and the aim of the current experiment was to examine the extent to which epistemic actions aid generation when the productiveness of the letter sets is known beforehand. In addition, the current experiment extended the experiment of Maglio *et al.* (1999), and Experiment 1 of current study, by including a third letter set as an additional stimulus, thus increasing the external validity of the experiment.

The second aim of this experiment was to test the hypothesis that the occurrence of the reversal of the epistemic action effect for the two letter sets across the two languages occurs as a result of the reactive inhibition that is applied to L1 when the task is performed in L2. This effect could have occurred as a result of the mixed-design of the previous experiment, which resulted in the same two letter sets being used when the task was performed in both English and Afrikaans. If this is the case, then a move to a fully factorial design employing entirely different letter sets for both languages should eliminate the reversal of the epistemic action effect across both languages, such that a similar effect is obtained. In fact, the results of Experiment 2 of van Heuven *et al.* (1998) demonstrate that a mixed-design yields an increase in the effect of non-target language neighbours relative to a blocked design. In terms of this, the first hypothesis of the present experiment can be put forward:

Hypothesis 1: A move from a mixed to a fully factorial design would eliminate the reversal of the epistemic action effect observed in Experiment 1, such that a similar pattern of results is obtained for both English and Afrikaans.

In light of the findings of Experiment 1, hypotheses regarding the epistemic action effect in terms of number of words are difficult to put forward, as although Maglio *et al.* (1999) discovered a significant main effect for letter manipulation, Experiment 1 of the present research did not. Whether or not the effect would occur in the present experiment is therefore difficult to predict on the basis of these contradictory findings. On the basis of the results of Maglio *et al.* (1999) and Experiment 1 of the present research, an interaction effect may possibly be predicted, especially considering that physical manipulation aided in word production for the set from which the least amount of words could be produced in the Maglio *et al.* (1999) experiment. However, Maglio *et al.* (1999) and Experiment 1 of the present research used two letter sets, whereas the current experiment uses three. It is therefore difficult to predict on the basis of prior research whether or not an interaction effect will occur when three as opposed to two stimuli are used.

No significant main effect of manipulation on the average length of the words produced was discovered in either the Maglio *et al.* (1999) experiment, or in Experiment 1 of the current study, and thus no effect for average word length is predicted.

Since a significant main effect was discovered for letter set in Experiment 1, and considering that it was found in the Maglio *et al.* (1999) experiment that letter manipulation aided production from the set from which less words could be produced, even though a significant main effect for letter set was not obtained in that study, hypotheses concerning the effect of letter set are easier to put forward. The second and third hypotheses of the present experiment are therefore:

Hypothesis 2: More words would be produced from the letter strings which have higher computed productiveness relative to the other letter strings, and this would occur for both English and Afrikaans.

Hypothesis 3: The performance of epistemic actions would aid word production more from the letter string which has the lowest level of computed productiveness relative to the two other sets, for both English and Afrikaans.

4.2 Method

4.2.1 Participants

Participants were 97 undergraduate psychology students from the University of Cape Town, who participated in exchange for course credit through the Student Research Participation Programme at the University of Cape Town, and all reported normal or corrected-to-normal vision. Participation in Experiment 1 was an exclusion criterion for participation in this experiment. In order to qualify for participation, participants had to speak English as a first language, and to have taken and passed Afrikaans as a second language at Grade 12 level. The preceding information was gathered from participant self-reports. As with Experiment 1, no demographic statistics were collected, however the sample again consisted of both men and women (with the majority of participants being female) of various ethnic groups, with the majority of participants being in their early twenties (see Section 3.4.1 of Experiment 1 for a discussion of why sex, ethnic group membership, and age is not expected to influence the results). Of the participants, 87 reported speaking English as a first language. Three spoke Zulu as a first language, two spoke Afrikaans, two spoke Xhosa, two Pedi, and one Setswana (see Chapter 3, Section 3.4.1 for a discussion of why possessing a third lexicon is unlikely to influence the results).

4.2.2 Experimental Design

A 2 (*letter manipulation* – 'Hands' versus 'No Hands') X 3 (*letter set* – set 1 versus set 2 versus set 3) factorial design was employed, with both factors being between-subjects factors. As with Experiment 1, this experiment was sub-divided into two parts: For Experiment 2.1, participants were required to perform the task in their home language (English); for Experiment 2.2, participants were required to perform the task in their second language (Afrikaans). Each participant was randomly assigned to one of the six conditions for Experiment 2.1, and one of the six conditions for Experiment 2.2. Again, a time limit of five minutes for each condition was set. The independent and dependent variables for this experiment were exactly the same as those for Experiment 1.

4.2.3 Apparatus

As with the previous experiment, seven tiles from the board game 'Scrabble' were utilised as stimuli. As the aim of this study was to compare the actual productiveness of letter sets across the two letter manipulation conditions to the absolute productiveness of the sets across both conditions, a more complex procedure which required determining *a priori* how many words could be made from a particular letter set was employed to select the particular sets used as stimuli for this experiment.

Selection of letter sets:

In order to calculate *a priori* the productiveness of the sets, a computer program was developed based on a modified version of the computational algorithm discussed in Jordan and Monteiro (2003). This algorithm produces anagrams from core strings (which may be words or non-words) from any suitable user-defined source vocabulary by taking in each string and outputting from each all possible words that exist in the source vocabulary. The source vocabulary may be in any language. The modified version of the algorithm is presented in Appendix B.

For the purposes of the present study, the core strings were 200 randomly generated sets of seven letters, which were then randomly sub-divided into two lists of 100 sets. One list was used as input when the program was run using an English source vocabulary; the other when the program was run using an Afrikaans source vocabulary.

The English source vocabulary employed was taken from release 4.0 of *12dicts*, a collection of six English word lists downloadable for free from http://wordlist.sourceforge.net/12dicts-readme.html. The afore-mentioned website contains background information on how the lists were constructed. Of the six lists the one entitled '2of4brif' was used, as it contains 60 387 words that do not include abbreviations, acronyms, hyphenations, names, or phrases, and thus excludes words that participants are instructed they are not allowed to construct (see Section 3.4.4 of Chapter 3 for an explanation of the experimental procedure). Moreover, the '2of4brif' list contains British English, the spelling of which is used in South Africa. This becomes especially important considering that the South African and British spelling of words such as *colour* contains a *u*, whereas the American English spelling of such words does not, and factors such as this would influence the computed productiveness of the input strings.

The source vocabulary used for Afrikaans was a modified version of the Webster's online Afrikaans dictionary, obtained from http://www.websters-online-dictionary.org/definition/Afrikaans-english. The dictionary was modified by deleting all abbreviations, acronyms, hyphenations, names, and phrases in order to render the English and Afrikaans source vocabularies largely equivalent.

The complete lists of strings, along with the computed productiveness of each string, are presented in Appendix C. eleven strings were deleted from the list of results for Afrikaans as no words were able to be made from those sets. In addition, both lists contained one letter set each that was a high outlier, and these sets were subsequently deleted from the lists. Descriptive statistics for the two revised lists are presented in Table 14 below.

In order to prevent sets with an extremely low level of productiveness to unduly influence the results, sets with a computed productiveness of more than one standard deviation below the mean were excluded. For the English list, this resulted in the exclusion of 14 sets of a computed productivity of 11.37 or less; for the Afrikaans list, 14 sets with a computed productiveness of 5.80 or less were excluded.

Table 14.

Descriptive Statistics for Computed Productiveness

	N	*M*	*Mdn*	*SD*
English	99	26.44	24	15.07
Afrikaans	89	13.52	13	7.73

From the remaining letter sets, three were randomly selected as experimental stimuli. One set was selected as a practice stimulus to be used for both the English and Afrikaans conditions. As the experimental procedure entailed a switch from one language to another, the practice set was randomly selected from the list of English sets, as research examining language-switching has demonstrated that it is more difficult to switch from a second language to a first than vice-versa (Costa & Santesteban, 2004). As the mean productiveness of the English sets was higher than that of the Afrikaans sets, selection of a practice stimulus from the English as opposed to the Afrikaans list would therefore more likely bias lexical access in the direction of English when the switch from Afrikaans occurs. This letter set was 'EEPRIWO,' and had a computed productiveness of 41 words for English. The experimental letter sets, and their computed productiveness, are displayed in Table 15 below.

Table 15.

Experimental Stimuli for Experiment 2

English	Afrikaans
1. EARNLEE (26)	1. FEVTDHS (6)
2. ECVNYOP (34)	2. IRIAGRK (8)
3. RTSDLEE (47)	3. YRNIRAE (13)

Note. Values in parentheses represent the computed productiveness of each letter set.

4.2.4 Procedure

Each experimental session was run in one of the three same dedicated rooms as used for Experiment1, lasted approximately 45 minutes and comprised between one and five participants run simultaneously. The instructions to participants were exactly the same as those given to participants for Experiment 1 (see Section 3.4.4 of Chapter 3 for a discussion of the instructions). As each participant performed one of the six conditions for Experiment 2.1 and one of the six conditions for Experiment 2.2, the order in which the conditions were performed was counterbalanced across participants.

As with Experiment 1, each session began with a practice trial, using the practice stimulus, which was performed in the same *letter manipulation* condition as the test trial. After the practice, each participant performed one of the two same distractor tasks used in Experiment 1 (see Section 3.4.4 of Chapter 3, and Appendix A for a discussion of the distractor tasks). The order of performance of the distractor tasks was counterbalanced across participants. After the distractor, each participant then performed the test trial, then the other distractor task, then another practice trial in the same *letter manipulation* condition that they were to perform the second test trial in, which was succeeded by performance of the first distractor task again. The session ended with the final test trial. The procedure can be represented as follows:

Practice1 → Distractor 1 → Test trial 1 → Distractor → Practice 2 → Distractor 1 → Test trial 2

As with Experiment 1, the Babcock Story Recall task was performed in English each time in order to avoid an imbalance of loading in working memory. In addition, performing the task in English would hopefully prime lexical access in the direction of English and thus counter the asymmetrical switching costs incurred when switching from Afrikaans to English. Again as with Experiment 1, all English words created were checked for legality using the online version of the Oxford English Dictionary (www.oed.com), and all Afrikaans words created were checked for legality using the Webster's online Afrikaans-English dictionary (www.websters-dictionary-online.org/definition/Afrikaans-english).

4.3 Results

4.3.1 Experiment 2.1

This experiment was a follow-up study to Experiment 1.1, and aimed to examine the effect that manipulating the productiveness of the letter sets used as stimuli had on the number of words produced, and the average length of those words, and to determine if there was any interaction between performing epistemic actions and the productiveness of the letter sets. Inspection of the data indicated that 10 participants did not speak English as a first language, and these participants were subsequently excluded from this analysis.

4.3.1.1 Effect of epistemic actions and letter set on word production and length

To test whether or not performing epistemic actions has an effect not only on the number of words made from a letter set of a given productiveness, but also the average length of the words made, when the task is performed in English, a 2 (*letter manipulation* – 'Hands' versus 'No Hands') X 3 (*letter set* – set 1 versus set 2 versus set 3) factorial ANOVA was conducted.

Number of words produced:

Descriptive statistics for this analysis, and a summary of the results, are given in Tables 16 and 17 below.

Table 16.

Descriptive Statistics for Number of Words Produced

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. EARNLEE	13	10.85	2.38	16	11.19	2.66
2. ECVNYOP	15	10.47	3.11	14	7.64	2.13
3. RTSDLEE	16	12.25	2.65	13	11.38	5.09

Table 17.
Analysis of Variance for Number of Words Produced

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	2.77	.03	.099
Letter Set (LS)	2	6.02**	.12	.004
LM X LS	2	1.89	.04	.156
Error	81	(9.69)		

Note. Values in parentheses represent mean square errors.
$*p < .05$. $**p < .01$.

As with Experiment 1.1, no significant main effect for *letter manipulation* was evident in this analysis, $F(1, 81) = 2.77$, $p = 0.099$, although more words were made from the 'Hands' condition ($M = 11.23$) than the 'No Hands' condition ($M = 10.09$). A significant main effect for *letter set* (shown in Figure 5) was evident, $F(2, 81) = 6.02$, $p = 0.004$, $\eta^2 = 0.07$.

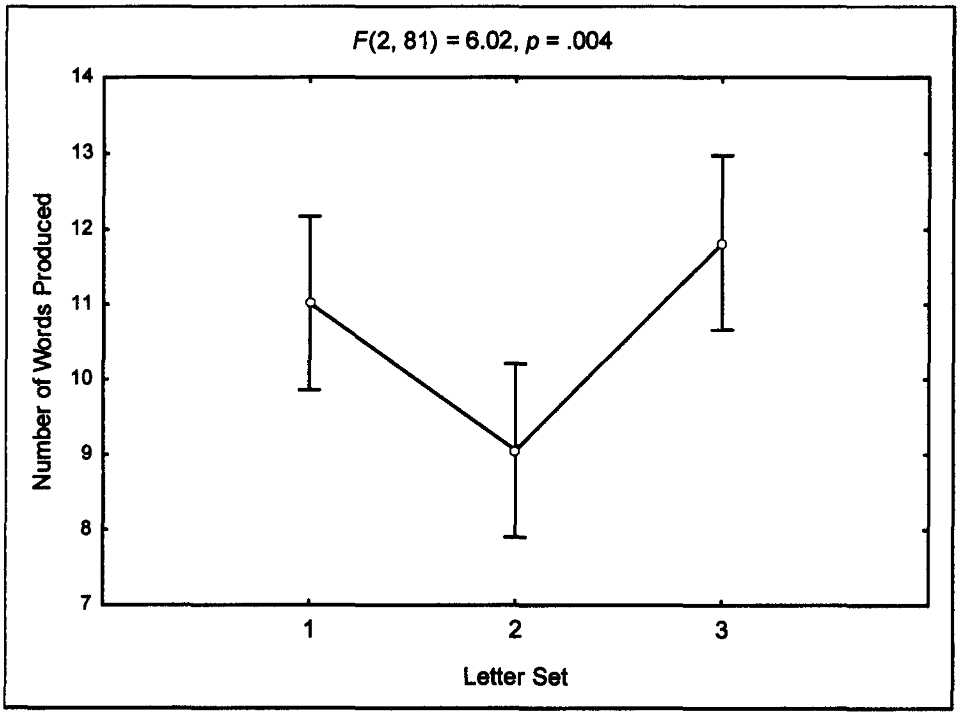

Figure 5. Means plot of the main effect of *letter set* on number of words produced.

Inspection of the Fisher LSD matrix revealed that significant differences exist between set 1 ($M = 11.03$) and 2 ($M = 9.10$), $p = 0.021$ as well as between sets 2 and 3 ($M = 11.86$), $p < 0.001$. No significant difference between sets 1 and 3 was observed, $p = 0.314$. No significant interaction effect between *letter manipulation* and *letter set* was evident, $F(2, 81) = 1.89$, $p = 0.156$.

Average word length:

Descriptive statistics, and a summary of the results from this analysis, are given in Tables 18 and 19 below.

Table 18.

Descriptive Statistics for Average Word Length

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. EARNLEE	13	3.74	0.12	16	3.74	0.15
2. ECVNYOP	15	3.50	0.20	14	3.41	0.25
3. RTSDLEE	16	3.91	0.29	13	3.67	0.35

Table 19.

Analysis of Variance for Average Word Length

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	4.55*	.04	.036
Letter Set (LS)	2	16.69**	.27	<.001
LM X LS	2	1.81	.03	.169
Error	81	(0.06)		

Note. Values in parentheses represent mean square errors.
*$p < .05$. **$p < .01$.

In contrast to Experiment 1, a significant main effect for *letter manipulation* was evident, $F(1, 81) = 4.55$, $p = 0.036$, indicating that words of a slightly longer length were produced from the 'Hands' ($M = 3.72$) compared to the 'No Hands' ($M = 3.61$) condition, although the effect size was very small, $\eta^2 = 0.04$. A significant main effect for *letter set* was observed, $F(2, 81) = 16.69$, $p < 0.001$, $\eta^2 = 0.28$, with the plot of means, shown in Figure 6, having the same general pattern as that of the plot for the number of words produced. Inspection of the Fisher LSD matrix indicates significant differences between sets 1 ($M = 3.75$) and 2 ($M = 3.46$), $p < 0.001$, as well as between sets 2 and 3 ($M = 3.80$), $p < 0.001$. As with the number of words produced, no significant difference between sets 1 and 3 was discernable, $p = 0.376$. As with the number of words produced, no significant interaction effect was detected, $F(2, 81) = 1.81, p = 0.169$.

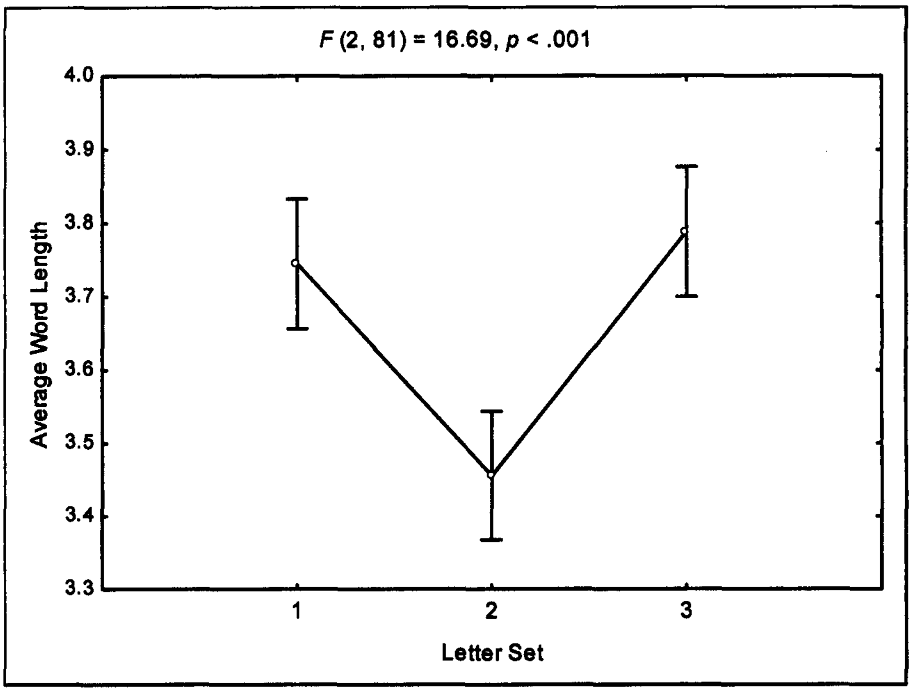

Figure 6. Means plot of the main effect of *letter set* on average word length.

4.3.1.2 Effect of epistemic actions and letter set on the average verbal and written frequency of the words produced

A 2 (*letter manipulation* – 'Hands' versus 'No Hands') X 3 (*letter set*- set 1 versus set 2 versus set 3) factorial ANOVA was performed in order to examine if there were any significant differences between the average verbal and written frequencies of the words made from each of the letter sets. Descriptive statistics for this analysis are reported in Tables 20 and 22. The results (summarised in Tables 21 and 23) revealed no significant difference between *letter manipulation* for either Brown Verbal Frequency, $F(1, 81) = 0.18, p = 0.673$, or Kucera and Francis Written Frequency, $F(1, 81) < 0.01, p = 0.981$.

Table 20.

Descriptive Statistics for Average Brown Verbal Frequency

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. EARNLEE	13	89.49	50.43	16	73.61	47.08
2. ECVNYOP	15	367.38	140.34	14	411.69	228.64
3. RTSDLEE	16	91.27	63.54	13	94.96	56.46

Table 21.

Analysis of Variance for Average Brown Verbal Frequency

Source	*Df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	0.18	.00	.673
Letter Set (LS)	2	63.75**	.61	<.001
LM X LS	2	0.49	.02	.613
Error	81	(13 802)		

Note. Values in parentheses represent mean square errors.
*$p < .05$. **$p < .01$.

Likewise, no significant interaction effect for either verbal frequency, $F(2, 81) = 0.49$, $p = 0.613$, or written frequency, $F(2, 81) = 0.89$, $p = 0.415$ was observed. However, the results indicate not only a significant difference between the three letter sets for Brown Verbal Frequency, $F(2, 81) = 63.75$, $p < 0.001$, $\eta^2 = 0.61$ (displayed in Figure 7) but also for Kucera and Francis Written Frequency, $F(2, 81) = 18.51$, $p < 0.001$, $\eta^2 = 0.31$ (shown in Figure 8).

Table 22.

Descriptive Statistics for Average Kucera and Francis Written Frequency

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. EARNLEE	13	488.39	263.31	16	369.29	211.52
2. ECVNYOP	15	606.37	332.76	14	669.19	525.81
3. RTSDLEE	16	147.86	68.12	13	199.67	87.97

Table 23.
Analysis of Variance for Average Kucera and Francis Written Frequency

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	<0.01	.00	.981
Letter Set (LS)	2	18.51**	.31	<.001
LM X LS	2	0.89	.02	.415
Error	81	(84 075)		

Note. Values in parentheses represent mean square errors.
$^*p < .05$. $^{**}p < .01$.

For the Brown Verbal Frequency, inspection of the Fisher LSD matrix indicated significant differences between sets 1 ($M = 80.73$) and 2 ($M = 388.77$), $p < 0.001$, and also between sets 2 and 3 ($M = 92.93$), $p < 0.001$. No significant difference between sets 1 and 3 was observed, $p = 0.694$. For Kucera and Francis Written Frequency, significant differences were observed between all three sets, with a difference between sets 1 ($M = 422.67$) and 2 ($M = 636.69$), $p = 0.006$, sets 1 and 3 ($M = 171.08$), $p < 0.001$, and sets 2 and 3, $p < 0.001$.

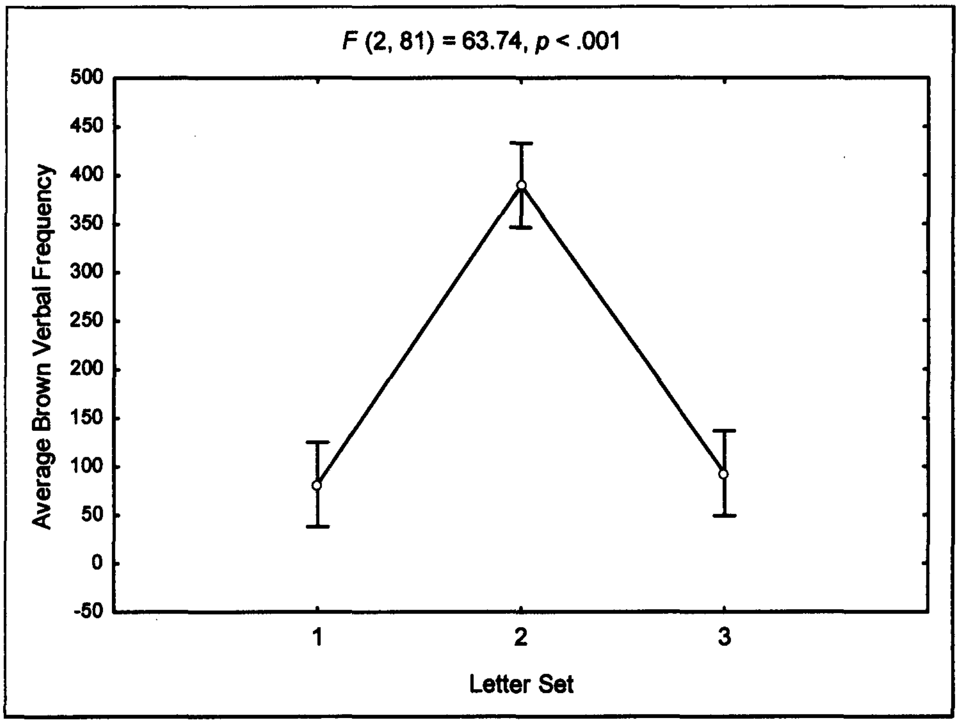

Figure 7. Means plot of the main effect of *letter set* on the average Brown Verbal Frequency of the words produced.

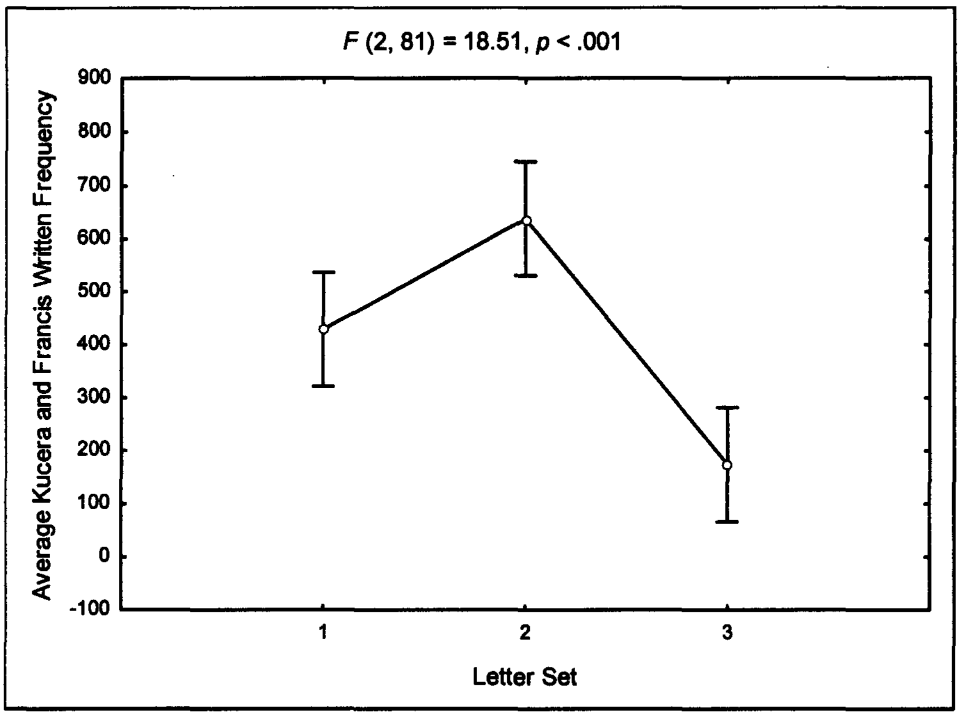

Figure 8. Means plot of the main effect of *letter set* on the average Kucera and Francis Written Frequency of the words produced.

4.3.2 Experiment 2.2

This experiment was a follow-up study to Experiment 1.2, and aimed to examine the effect that manipulating the productiveness of the letter sets had not only on the number of words produced from each set, but also the average size of those words produced. In addition, the aim was to determine if there was any interaction between the performance of epistemic actions and the productiveness of the sets used as stimuli. Whereas Experiment 2.1 involved participants performing the task in their first language (English), this experiment required participants to perform the task in their second language (Afrikaans). The participants who were excluded from the analysis in Experiment 2.1 were subsequently included in this analysis.

4.3.2.1 Effect of epistemic actions and letter set on word generation and length

To test whether or not performing epistemic actions has an effect not only on the number of words made from a letter set of a given productiveness, but also the average length of the words made, when the task is performed in Afrikaans, a 2 (*letter manipulation* – 'Hands' versus 'No Hands') X 3 (*letter set* – set 1 versus set 2 versus set 3) factorial ANOVA was conducted.

Number of words produced:

Descriptive statistics, and a summary of the results from this analysis, are given in Tables 24 and 25 below. As with Experiment 2.1, no significant main effect for *letter manipulation* was evident, $F(1, 91) = 0.49$, $p = 0.482$. Again as with Experiment 2.1, a significant main effect for *letter set* (displayed in Figure 9) was observed, $F(2, 91) = 10.92, p < 0.001, \eta^2 = 0.19$.

Table 24.

Descriptive Statistics for Number of Words Produced

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. FEVTDHS	17	3.00	1.22	17	3.59	1.23
2. IRIAGRK	17	1.82	1.88	14	1.79	0.89
3. YRNIRAE	15	2.87	1.25	17	2.88	1.11

Inspection of the Fisher LSD matrix revealed the same pattern of significance observed in Experiment 2.1, with significant differences between sets 1 (M = 3.29) and 2 (M = 1.81), $p < 0.001$, and between sets 2 and 3 (M = 2.88), p = 0.002, but no significant difference between sets 1 and 3, p = 0.198. No significant interaction effect between *letter manipulation* and *letter set* was evident, $F(2, 91) = 0.58$, p = 0.563.

Table 25.
Analysis of Variance for Number of Words Produced

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	0.49	.00	.482
Letter Set (LS)	2	10.98**	.19	< .001
LM X LS	2	0.58	.01	.563
Error	91	(1.72)		

Note. Values in parentheses represent mean square errors.
*p < .05. **p < .01.

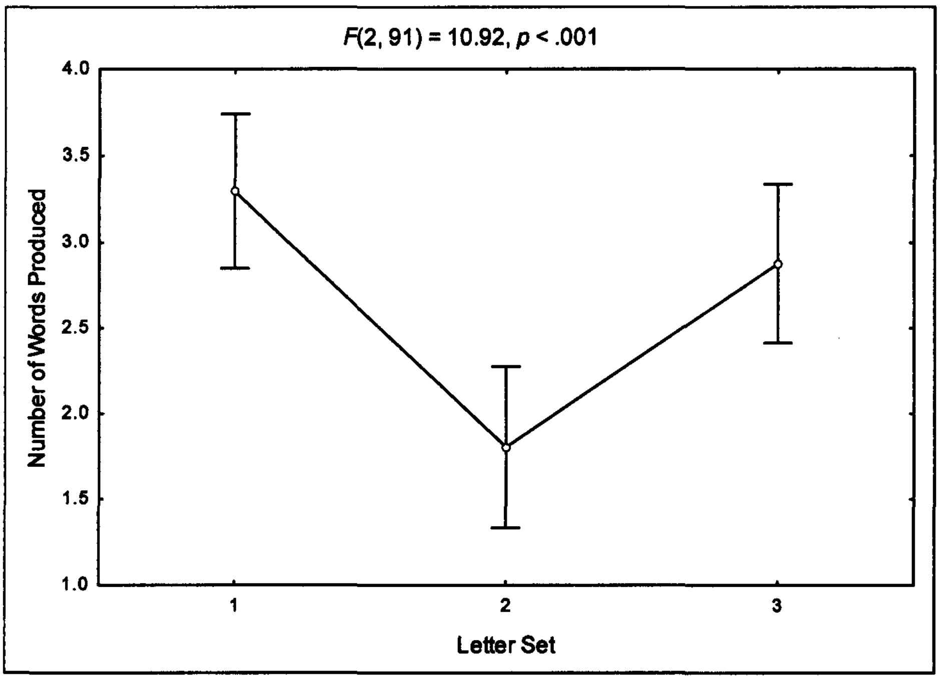

Figure 9. Means plot of the main effect of *letter set* on number of words produced.

Average word length:

Descriptive statistics, and a summary of the results, are reported in Tables 26 and 27 below. For this analysis no significant main effect for either *letter manipulation*, $F(1, 91) = 0.32, p = 0.571$, or *letter set*, $F(2, 91) = 1.60, p = 0.207$ was found. Likewise, no significant interaction effect was detected, $F(2, 91) = 0.84$, $p = 0.436$.

Table 26.

Descriptive Statistics for Average Word Length

	Letter Manipulation					
	Hands			No Hands		
Letter Set	*n*	*M*	*SD*	*n*	*M*	*SD*
1. FEVTDHS	17	2.70	0.32	17	2.62	0.25
2. IRIAGRK	17	2.79	1.37	14	3.17	1.00
3. YRNIRAE	15	2.71	0.51	17	2.68	0.52

Table 27.

Analysis of Variance for Average Word Length

Source	*df*	*F*	η^2	*p*
Letter Manipulation (LM)	1	0.32	.00	.571
Letter Set (LS)	2	1.603	.03	.207
LM X LS	2	0.84	.02	.436
Error	91	(0.59)		

Note. Values in parentheses represent mean square errors.
$^*p < .05$. $^{**}p < .01$.

4.4 Discussion

4.4.1 Experiment 2.1

As with Experiment 1.1, a significant main effect for letter manipulation was not obtained in this experiment. In contrast to Experiment 1.1, no significant interaction effect was obtained, although as with that experiment, a significant main effect of letter set was again obtained, although this time it was expected due to the manipulation of the productiveness of the letter sets.

The finding concerning the main effect of letter manipulation on the average length of the words produced is surprising, considering that this effect was not predicted on the basis of the results of the original Maglio *et al.* (1999) study, or on the basis of the results of Experiment 1 of the present study. However, this effect could be predicted on the basis of the model presented in Chapter 2, in which physical manipulation is said to aid in the application of the operators that are required to compose words in a search strategy, as when physical manipulation is allowed these operators can be applied physically with potentially less computational cost compared to applying them mentally. It should be noted, however, that the effect size for the main effect of letter manipulation on average word length was very small (η^2 = 0.04), thus demonstrating that although manipulation does aid in the production of words of a slightly longer length, it does so to only a small extent.

With regards to the significant main effect of letter set, it was discovered that the number of words produced from set 2 was significantly lower than the number of words produced from sets 1 and 3, from which an approximately equal amount of words were produced. This finding provides further evidence that the particular letter sets used as stimuli do in fact influence the number of words produced.

Alternatively, this shows that the productivity manipulation failed to work as predicted, especially considering the lack of a significant interaction effect, as this finding is surprising considering that if the three letter sets are ranked in order of productiveness from least (set 1) to most productive (set 3), it would be expected that the number of words produced from each of the three letter sets would approximate a linear increasing function of the computed productiveness of the sets. Instead, a U-shape results from the ranking of the sets in order of productiveness (see the current Chapter, Figure 5). However, the most number of words were produced from set 3, which had the highest level of computed productiveness, which does provide some indication that the computed productiveness of the letter string does influence the actual number of words produced. Furthermore, this also provides evidence that this influence can also be separate from the physical manipulation of the stimuli, as no significant interaction effect was obtained in this experiment.

An examination of the Fisher LSD matrix indicated that approximately equal amounts of words were generated from letter sets 1 and 3, and in fact no statistically significant difference between these two letter sets was obtained. A possible explanation for this rests in the frequency of the words produced from each set, as although there was a significant difference in the written frequency of the words produced from each of these sets, words of approximately equal spoken frequency were produced from both sets, and as noted in the discussion for Experiment 1, frequency effects are likely to influence the number of words produced. Although the difference in the pattern of results relating to the spoken and written frequency of the words produced from each letter set was not predicted on the basis of Experiment 1, in which the results for both frequencies were essentially similar, a difference in the pattern of results for both types of frequencies which is observed here is not completely unexpected, as they are different types of frequencies and thus slightly different measures.

A surprising finding concerning the frequency effects and the number of words produced relates to the fact that the lowest number of words were produced from letter set 2, the set from which words with the highest overall frequency were produced, compared to letter sets 1 and 3, and the difference between the number of words produced from this set and those sets was statistically significant. This was not expected, as this set should therefore have resulted in the most number of words being produced. One possible explanation for this relates to the computed productiveness of each set, such that letter set 2 had a lower level of computed productiveness compared to letter set 3. Thus, although the words produced from set 3 were of a lower frequency than the words produced from set 2, more words were produced from set 3 as a result of the fact that more words were *supposed* to be producible.

This does not explain the finding of the significant difference between letter sets 1 and 2, as fewer words were computed to be producible from set 1 relative to set 2, where in fact more words were produced from set 1 relative to set 2. A possible explanation for this resides in the stimuli themselves. Letter set 2 was 'ECVNYOP,' in which no words are instantly discernable. Letter set 1 was 'EARNLEE,' in which the word *earn* is instantly discernable, and this word would therefore have most likely been generated by the majority of the participants, which may have influenced the results. To test this hypothesis, a re-analysis of the data with the word *earn* deleted from the list of words produced by the participants was carried out, and the results indicate that the significant difference between letter sets 1 and 2 observed in the Fisher LSD matrix resolves in this case. In the original analysis the difference was statistically significant, $p = 0.021$, whereas in the re-analysis the difference drops to a non-significant level of $p = 0.189$[1].

As with Experiment 1 (see Chapter 3, Section 3.6.1), the above-mentioned difference between letter sets 2 and 3 may also be explainable in terms of the fact that first letter predicts anagram solution time such that solutions are obtained quicker when the word begins with a consonant rather than a vowel (Gilhooly & Johnson, 1978), in that letter set 3 ('RTSDLEE') began with a consonant but letter set 2 ('ECVNYOP') began with a vowel.

[1] The re-analysis does not result in any changes in the pattern of results for anything else. The lack of a main effect of *letter manipulation* remains, $F(1, 91) = 3.13, p = 0.081$ compared to $F(1, 91) = 2.77, p = 0.099$ in the original analysis. The main effect for *letter set* remains, $F(2, 91) = 5.88, p = 0.004$ compared to $F(2, 91) = 6.02, p = 0.004$ in the original analysis. The non-significant interaction effect also remains, $F(2, 91) = 1.76, p = 0.178$ compared to $F(2, 91) = 1.89, p = 0.156$ in the original analysis. The significant difference between letter set 2 and 3 in the Fisher LSD matrix also remains, $p < 0.001$ compared to $p < 0.001$ in the original analysis. The difference between sets 1 and 3 now becomes significant, however, $p = 0.039$ compared to the non-significant difference in the original analysis, $p = 0.315$. This could be expected on the basis of the significant difference between sets 2 and 3 obtained in both the original and the re-analysis of the data, that is, that since a significant difference between sets 2 and 3 exists, if the significant difference between sets 1 and 2 resolves, this thus induces a difference between sets 1 and 3.

Another pertinent finding concerns the discovery of a significant main effect of letter set on average word length, such that words of a longer average length were made from sets 1 and 3 than from set 2. This finding can be explained by appealing to the frequency of the words that were produced from each of the letter sets. According to (Vitevitch & Rodriguez, 2005), there is a negative relationship between length and frequency in English, such that words that occur more often tend to be shorter than words which occur less often. The results indicated not only a significant main effect of letter set on the average spoken frequency of the words produced, but also a significant main effect on the average written frequency. As predicted on the basis of the negative relationship between length and frequency, this effect was in the opposite direction to that observed for the effect on word length, such that the words produced from set 2 were of a significantly higher frequency than the words produced from sets 1 and 3. In terms of the model discussed in Chapter 2 which incorporates elements of the Interactive Activation model of McClelland and Rumelhart (1981), higher frequency words have higher average baseline resting levels of inhibition, and thus are easier to 'see' in the letter string and so pop-out more easily. This results in a length effect in terms of the finding that initial attempts at solution result in most shorter words being solved (Gavurin & Zangrillo, 1975). In the case where the words generated were of a lower frequency, it is more likely that the number of pop-outs that occurred was fewer, and thus more words may have been formed on the basis of a letter rearrangement strategy, which would result in words of a slightly longer length being produced.

4.4.2 Experiment 2.2

Unlike Experiment 2.1, no significant main effect for letter manipulation was obtained either for number of words produced or average word length. The fact that no significant main effect for letter manipulation was again obtained provides evidence that epistemic actions do not always aid in task performance in every context and situation. This was in fact predicted in terms of the model of interactive Scrabble skill presented in Chapter 2. In this model, physical manipulation may increase the amount of activation of neighbours in L1, which would then in turn activate the L1 language node which would inhibit all L2 words, in which case physical manipulation would *increase* the time taken to settle on the target word. In terms of the model, the fact that physical manipulation would increase the time taken to settle on a target is predicted to occur in the first phase, where solutions pop-out. It remains to be shown then that most of the solutions that occurred in this experiment were pop-out solutions. According to the model, this phase also predicts length effects, in that pop-out words should be shorter. In the current experiment, no significant main effect for word length was discovered for either letter manipulation or letter set, and neither was any significant interaction obtained. Inspection of the means indicates that all words formed for this experiment were three letters or less, thus the words produced were short. This can be taken as an indirect indication that the words produced were likely produced as a result of pop-out solutions rather than search solutions.

Another possible explanation, given below, can be sought in terms of the difficulty of producing words from the letter sets used as stimuli in this part of the current experiment, in that it was extremely difficult to produce words from all three letter sets, indicated not only by the computed productiveness, but also by the actual productiveness of the letter sets.

This explanation is as a result of the fact that there are undoubtedly costs involved in performing mental manipulations and operations on stimuli, but that there are also costs in involved in performing physical actions. The reason why epistemic actions are supposed to aid in task performance is that the benefits of taking action outweigh the costs of mental manipulation. For example, a pilot study conducted by Kirsh and Maglio (1994) found that it takes around 800 to 1 200 milliseconds to mentally rotate a Tetris piece 90 degrees, but only 100 milliseconds to physically rotate a Tetris piece. However, research (e.g., Maglio *et al.*, 2003) has demonstrated that there is also a cost to performing epistemic actions. The epistemic action hypothesis is thus predicated on the fact that the performance of extra actions outweighs not only the costs involved in mental computation, but also the costs involved in performing the actions themselves. Although studies such as those of Kirsh and Maglio (1992a, 1994) and Maglio *et al.* (2003) have demonstrated that the performance of epistemic actions do indeed outweigh both types of costs, all these studies have examined the performance of actions either on experts (e.g., Kirsh & Maglio, 1994), or participants who are made to practice the task for a certain period beforehand such that they achieve a sufficient level of proficiency in the task (e.g., Maglio & Kirsh, 1996).

Studies on epistemic action have discovered that the performance of epistemic action increases with skill (e.g., Maglio & Kirsh, 1996), that is, individuals more skilled at a task take more actions. The reason for this is not explicated anywhere in the epistemic action literature, although it is a finding that warrants explaining. The reason why experts compared to non-experts take more physical actions may be as a result of the fact that they are able to trade their expertise against the costs of performing the actions. The development of expertise within a particular domain is said to result in the development of automatic processing within that domain (Newell & Rosenbloom, 1981) such that practice improves performance in accordance with a power function of practice time or practice trials (Maglio & Kirsh, 1996). Thus, the costs of mental computation are already reduced in experts, and it may therefore be that the extra costs involved in performing epistemic actions are traded against the already reduced costs of mental computation such that a net benefit accrues. In the case where an individual is not an expert in a particular task, the cost of performing the mental computations is greater, and this combines with the increase in cost associated with performing actions to render the benefits of performing epistemic actions null, or the performance of physical action may actually complicate the computations required in performing a task such that they have the opposite effect.

Although the present experiments did not consider expertise, how this applies to the present set of results is that considering English was a first language for the participants in this task, and that processing of words is more automatic in the case involving a first language as lexical representations are more unitised (Carr, 1992), this automatic processing can therefore be traded against the extra cost associated with performing physical action such that a net benefit accrues. However, even in this case the benefit is small, as evidenced by the small effect sizes obtained. In the case of a second language, in which word processing is less automatic, there is no automaticity of processing to be traded against the extra cost of performing physical manipulation, and no net benefit accrues.

The second pertinent finding in the present set of results is that as with Experiment 2.1, a significant main effect for letter set was evident, indicating that the particular letter set used as a stimulus influenced the number of words produced. In contrast to

Experiment 2.1 in which the most number of words were produced from the set of the highest computed productiveness, here the most number of words were produced from the set of the *lowest* computed productiveness. The reason as to why this occurs is unclear, although it may be as a result of frequency effects, considering that such effects were largely responsible for explaining the pattern of results observed in Experiments 1.1 and 2.1. However, as no frequency data was available for Afrikaans, this cannot be conclusively proven.

Another possible explanation for the fact that the most number of words were produced from the set of the lowest level of computed productiveness (letter set 1) could relate to the finding in the literature on anagram solution, which is incorporated into the model presented in Chapter 2, that search is more likely to begin with the initial letter of a word, and that this letter is more likely to be a consonant than a vowel as more words begin with consonants than vowels (Gilhooly & Johnson, 1978; Novick & Sherman, 2007). In the present experiment, letter set 1 ('FEVTDHS') began with a consonant, whilst letter set 2 ('IRIAGRK') began with a vowel. Although letter set 3 also began with a consonant ('YRNIRAE'), only thirteen non-hyphenated Afrikaans words begin with a 'Y' in the Webster's online Afrikaans dictionary. Although the finding that consonant-beginning words usually result in quicker solutions was obtained from English words (Gilhooly & Johnson, 1978) and participants (Novick & Sherman, 2007), as with English, Afrikaans has a regular orthography (Penn *et al.*, 2001), and thus the same explanation concerning the English results may also apply here.

The final pertinent finding of this experiment concerns the fact that the shape of the cell mean plots of the interaction between letter manipulation and letter set for both English and Afrikaans were similar, whereas in Experiment 1.1 and 1.2 the cell mean plots of the interaction effect for English and Afrikaans were reversed. In Experiment 1, this was explained as a result of the fact that since the same letter sets were used for both English and Afrikaans, and since the words from the set were of a lower average frequency in English, less reactive inhibition would need to be applied to the English words producible from this set, which would facilitate word production in Afrikaans and therefore lead to a reversed effect (see Chapter 3, Section 3.6.2). Although this can still not be conclusively proven as no measure of the possible amount of reactive inhibition applied was taken, the fact that in the current experiment the reversal effect disappears when different letter sets are used in the English and Afrikaans conditions provides some further evidence that the reversed effect on the letter sets in Experiment 1 most likely occurred as a result of the relative amount of reactive inhibition applied to each set.

4.5 Conclusion

The results of the present experiment provide some qualified support that the epistemic effect is reliable, as a main effect for letter manipulation was obtained in Experiment 2.1. However, the lack of a main effect for letter manipulation in Experiment 2.2 demonstrates that this effect does not always occur, and that the results of Experiment 2.1 do not amount to unqualified support for the epistemic action hypothesis. The main effects for letter set obtained in both analyses provides a further indication that the letter strings used as stimuli do in fact exert a reliable influence on the number of words produced, and in the case of English, on the length of those words produced. Furthermore, the finding of a disappearance of the apparently reversed effect for the English and Afrikaans results that appeared in Experiment 1 provides some evidence towards the conclusion that that effect possibly occurred as a result of reactive inhibition, since the two same letter sets were used in that experiment for both languages whereas different stimuli were used for both languages in the current experiment. The next presents a general discussion of the results obtained from both Experiments, and the implications of these for the epistemic action hypothesis and the model presented in Chapter 2.

Chapter 5

General Discussion

5.1 The Epistemic Action Effect

Epistemic actions are physical actions which an agent takes in order to off-load cognitive work to its environment in order to increase the speed, accuracy, and robustness of mental computation. An everyday example of this would be laying out the pieces of something that requires assembly in roughly the order and spatial relationship they will have in the final product (Wilson, 2002).

Previous research in the domain of Tetris (e.g., Kirsh & Maglio 1994; Maglio & Kirsh, 1996; Maglio & Wenger, 2000, 2002) has revealed that taking these physical actions can improve performance in this task. However, performance in Tetris is inherently spatial in nature, and this research suffers from the bias inherent in the epistemic action viewpoint of a focus only on the way in which physical actions can improve performance at spatial tasks. Nearly all research in the domain of epistemic action has focused on Tetris, with it remaining to be shown that the theory that epistemic actions enhance task performance can be applied to other domains, such as inherently verbal tasks. If off-loading is only useful for tasks that are themselves spatial in nature, then its range of applicability as a cognitive strategy is limited (Wilson, 2002). It is still extremely useful, however, but if it is limited to spatial tasks then it may be more of a way of running simulations externally, which is slightly different to general off-loading of cognition.

The study undertaken by Maglio *et al.* (1999) on the performance of epistemic actions within a Scrabble-like task, as well as the present research which undertook to replicate and extend this study, is therefore of particular relevance as anagram solution requires visuospatial ability in terms of the ability to mentally manipulate the letters (Halpern & Wai, 2007) and previous research (e.g., Gavurin, 1967) has provided evidence that physical rearrangement of the stimuli in an anagram leads to a reduction in the amount of spatial processing required for performance in an anagram task. Verbal ability is also required not only in terms of the fact that rapid retrieval of words from the lexicon is needed (Halpern & Wai, 2007), but also in terms of the fact that anagram solution requires matching the presented letters to the fit and spelling constraints of a particular language (Novick & Sherman, 2003, 2007). The experimental task used in Maglio *et al.* (1999), and the present research, therefore allows an examination of the way in which epistemic actions affect task performance when a processing requirement in addition to spatial processing is required.

The results of the present experiments demonstrate that when an additional processing requirement is entered into the task, the epistemic action effect does not always occur, and that it only seems to occur in the correct context. For example, a significant main effect was obtained only in Experiment 2.1 for average word length, whereas the epistemic action effect only occurred in Experiment 1.1 and 1.2 via an interaction effect. Furthermore, no significant main effect for letter manipulation occurred for the number of words produced in either Experiment 2.1 or 2.2, and did not occur for the average length of the words produced in Experiment 2.2. As the present set of experiments involved a word generation task, the verbal requirements more than likely outweigh the spatial requirements of the task, and the results of Experiment 1 therefore provide some evidence that when a task demand in addition to a spatial requirement is introduced, the epistemic action effect is reduced to a small level, as evidenced by the small effect sizes obtained throughout the experiments.

It may be that the reason such a small effect is obtained is that physical manipulation is aiding primarily with the spatial requirement of the task, and that since this requirement is likely to be relatively small compared to the verbal requirement, the resulting effect is thus quite small. However, considering that a multitude of factors such as vocabulary, word fluency, and knowledge of bigram frequencies are related to anagram solving ability (Mendelsohn & Covington, 1972), and a multitude of factors relating to the letter sets used such as orthographic neighbourhood (Novick & Sherman, 2007), and LTPs (Pinckney & Kwiatkowski, 1977), none of which were measured, could have potentially influenced the results, the fact that an effect for something as simple as physical manipulation is obtained provides evidence testifying to the reliability of the epistemic action effect, at least in certain instances.

However, the results of Experiment 2.2, where no effect for manipulation was obtained at all, allude to the fact that the effect may only be useful below a certain load of processing, as the processing requirements in the task used for this experiment were likely to be high not only as a result of the low level of computed productivity, but also the additional processing requirements induced by performing the task in a second language. As noted in the Discussion section of Chapter 4, a certain amount of automaticity of processing may be required in order for epistemic actions to aid performance, and when this automaticity is absent and the task demands fairly high, no effect of physical action on performance is obtained. However, this hypothesis has not been explicitly tested in either the present set of experiments or in the literature. For example, Maglio *et al.* (2003) examines the performance of epistemic action in Tetris only for periods of play where the game speed was relatively slow, and thus where the processing load induced by the task itself would have been relatively small.

5.2 Evaluation of the Model of Interactive Skill in Scrabble

Certain of the results of the present set of experiments, and the results of Experiment 1.2 in particular, provide evidence that physical manipulation aids in word production across a second language. This demonstrates that the effect is reliable, especially considering that the pattern of results across the two different languages were virtually identical, with no main effect for manipulation obtained, but a significant main effect for letter set and a significant interaction effect obtained. Likewise, it was discovered in the post-hoc analyses that manipulation aided production for only one of the two letter sets. When the effect size for this result ($\eta^2 = 0.25$) is compared with the effect size of manipulation for the letter set for which manipulation aided production in English ($\eta^2 = 0.14$), it is evident that manipulation has slightly more of an effect when the task is performed in a second language. This provides some evidence towards the hypothesis that physical manipulation may aid more when the task is performed in a second language. This was in fact predicted in the model on the basis that since L2 words have lower average resting levels of activation to begin with due to reduced frequencies as a result of the reduced exposure of bilinguals to their second language compared to their first (van Heuven *et al.*, 1998), in this case it may be expected that physical manipulation would aid more.

A result to the contrary was provided by Experiment 2.2, where the task was also performed in Afrikaans, in which no significant main effect for manipulation was evident. This possibility was also considered in the model, in that physical manipulation may increase the amount of L1 neighbours in the letter string such that an inhibitory effect on L2 occurs, and in this sense physical manipulation would have an inhibitory effect on word production. In addition, as described in Section 5.1 above, it may simply be that the task was far too difficult for manipulation to have any effect. More research is clearly needed to unpack the influence that the letter strings used have on the performance of physical manipulation. It is suggested that in future, whole-word anagrams in which the stimulus properties such as frequency and orthographic neighbourhood can be explicitly controlled are used.

Although the reason as to why manipulation would aid in generation for one of the letter sets for Experiment 1.2 but not for any of the letter sets in Experiment 2.2 cannot be explicitly proven, a possibility may rest in the concept of reactive inhibition developed by Green (1998, cited in Costa & Santesteban, 2004). In Experiment 1.2 it was discovered that what appears to be a reversed effect for the letter sets is apparent, such that for English, manipulation aids generation for set 2 but not set 1, but for Afrikaans, manipulation aids generation for set 1 but not set 2. Considering that the English words produced for set 2 were of a lower frequency, in terms of the concept of reactive inhibition they would have required less suppression in order for the production of Afrikaans words to occur. As noted, although this hypothesis cannot be explicitly proven, the fact that the seemingly reversed effect that occurs disappears in Experiment 2, where different letter sets are used for both English and Afrikaans, provides some evidence in favour of this conclusion. Considering that the model is based on a non-selective bilingual lexical access viewpoint, between-language interference effects were predicted, and the occurrence of a seemingly reversed pattern of results for the interaction effect in Experiment 1.2 compared to Experiment 1.1 provides some evidence towards a possible conclusion that between language interference effects do in fact occur in the task.

An interpretation in terms of the fact that this reversal of results is indicative of interference effects must be made with caution though, as it was noted in the Discussion in Chapter 3 that the possibility also exists that this is simply the same result as was obtained for Experiment 1.1, and it just so appears to be an opposite effect. In addition, research by van Heuven *et al.* (1998) has demonstrated that participants may be able to in some way control non-target language effects, which is in keeping with the 'language-specific selection threshold hypothesis' of Costa and Santesteban (2004), and the 'language mode' hypothesis, which states that a bilingual individual can pre-select the lexical system that they access (Grainger & Beauvillain, 1987). van Heuven *et al.* (1998) discovered, however, that the control of interference effects occurred only for highly proficient bilinguals, and similarly, Costa and Santesteban (2004) note that language specific selection may only occur in highly proficient bilinguals. Considering that it is unlikely that very few of the participants in the present experiment were highly proficient, it is therefore possible that the seemingly reversed effect is in fact as a result of the relative amount of reaction inhibition that needs to be applied to the words producible from each letter string.

However, caution in interpretation in this regard is also required especially in light of the fact that frequency effects occur, and no frequency data was available for the Afrikaans words produced. Thus, the fact that manipulation aided generation for set 2 in English and set 1 in Afrikaans may be as a result of the fact that the words producible from set 1 in Afrikaans are of a lower frequency, and that the seemingly reversed pattern of results is due to this, rather than the amount of reactive inhibition that is required to be applied in each case.

In terms of the model presented in Chapter 2, physical manipulation of the letter string is presumed to aid in the production of words via numerous possible mechanisms. In the first phase of the model, physical manipulation is said to aid in the generation of pop-out solutions primarily through facilitating these solutions via increasing the amount of excitation at the letter level, thus facilitating word recognition. Given that these solutions are simply pop-out solutions, and thus do not require many operations or processing resources to generate, physical manipulation at this stage is presumed to have a smaller effect. In the remaining stages of the model, in which a search process is entered into, operations are required to compose the words that are produced, and physical manipulation is said to aid production to a greater extent.

In terms of the fact that a small effect for physical manipulation is predicted in terms of the generation of pop-out solutions, it may be that physical manipulation extends the time-course over which pop-out solutions occur. In other words, physical manipulation may allow the generation of pop-out solutions to occur beyond the two seconds level of exhaustion proposed by Novick and Sherman (2003). However, this is unlikely considering that self-reports from individuals indicate that pop-out, search, and mixed strategies (i.e., pop-out solutions preceded by a search solution) are all used (Novick & Sherman, 2003), and that individuals in the Novick and Sherman (2003) study had at least one anagram solution in each category, indicating that a search strategy is used at least some of the time. Furthermore, if a word is not settled on within about two seconds the pop-out strategy thus fails, and the solver switches to a deliberate process of rearranging the letters, that is, a search strategy is entered into (Novick & Sherman, 2007).

Given the small effect sizes obtained, and the null effects obtained in two of the analyses, it is clear that physical manipulation does not have much of an effect, even in a search process. A possible explanation for this may be that physical manipulation in a search process aids only in off-loading the spatial requirements involved in extracting task-relevant chunks such that the chunks may be physically placed in the external world rather than held in working memory, and that physical manipulation in a search process which involves the application of operators to compose words aids in off-loading the spatial requirements involved in the composition and application of the operators such that this does not have to be performed in working memory. If this is the case, then a relatively small contribution from physical manipulation would also be expected, considering that the spatial aspect of a Scrabble-like task is smaller relative to the verbal aspect. A result which may be indicative of this is the very small effect size ($\eta^2 = 0.04$) of the main effect of letter manipulation on the average length of the words produced in Experiment 2.1.

The rest of the verbal search process, such as the formation of hypotheses about the correct letter order and the testing of these hypothesised partial reorganisation against words in the lexicon (Mendelsohn, 1976), may therefore proceed entirely mentally. In this sense, physical manipulation may possibly perform the simple function of error-checking, such that the mental reorganisation of the letter string into a possible word is checked by physically manipulating the stimuli into the hypothesised word. This is similar to the function performed by physical action in Tetris with regards to the translation of a zoid from its position in play to the wall and back again, which is to verify its placement in a certain column and thus reduce the probability of error of placement (see Kirsh & Maglio, 1994, pp. 539-541).

Although a main effect for physical manipulation did not materialise in either Experiment 1.1 or 1.2, an interaction effect between physical manipulation and letter set occurred such that performing actions aided word production only for one of the two letter sets. In the case of Experiment 1.1, manipulation facilitated production from the set from which the words produced were of a lower frequency, which was in fact predicted by the model. This prediction was made as a result of the fact that the model incorporates aspects of the Interactive Activation model of McClelland and Rumelhart (1981), in which lower frequency words have lower average resting levels of excitation, and therefore require more excitation to push them above the threshold of recognition. In terms of the model presented in Chapter 2, physical manipulation is said to provide this extra excitation by heightening the perceptibility of the letter-level units through changing the orthographic neighbourhood, thereby facilitating not only the production of a certain word, but also its neighbours, and thereby increasing the total number of words made.

Recent support for this conclusion comes from research by Novick and Sherman (2007), who discovered in a regression analysis that orthographic neighbourhood predicts the time to anagram solution such that words with more orthographic neighbours take less time to solve. Given the time limit inherent in the task, the less time it takes a participant to 'solve' (i.e., produce) a word from the presented letter string, the more words could subsequently be produced in the time available. Novick and Sherman (2007) also discovered that Kucera and Francis frequency was a reliable predictor, with higher frequency words taking less time to solve than lower frequency words. This provides additional support for the finding in the present research that physical manipulation aids word production more when the words producible from a given letter string are of a lower frequency, and that physical manipulation may not in fact have an effect when the words producible are of a higher frequency, and that in this case physical manipulation may actually impair performance.

Of particular importance for the present research is that factors such as orthographic neighbourhood and frequency are superficial characteristics of anagrams, and that these superficial characteristics in the Novick and Sherman (2007) study were found to influence anagram solution performance for search strategies more than pop-out solutions. Thus, the finding that the superficial characteristics of the letter string influence whether or not physical manipulation aids word production can therefore be taken as support for the proposal that manipulation does in fact aid in word production when a search strategy is used, considering that superficial characteristics influence a search more than a pop-out strategy.

Additional support for this conclusion can possibly be drawn from the finding in Experiment 2.1 of a significant main effect for letter manipulation on the average length of the words produced relative to the finding in Experiment 1.1 of no significant main effect of manipulation. In Experiment 1.1 only two letter sets were used as stimuli, with words of a low frequency being produced from only one of the two sets; in Experiment 2.1, where three letter sets were employed, the words producible from two of the three letter sets were of a low frequency. This could possibly have resulted in an overall greater influence of manipulation across the letter sets in Experiment 2.1, such that a significant main effect became apparent, considering that longer words are of a lower frequency, however, as no interaction effect was obtained, this conclusion cannot be conclusively proven.

A number of interesting findings concerning word length were also discovered in the present set of experiments. For Experiment 1.1, the length of words produced was in the opposite direction to that predicted the literature, which is that longer words are usually of a lower frequency. This is explainable in terms of the model and the effect that physical manipulation has on the neighbourhood density of the originally presented letter string. Specifically, the model predicts that physical manipulation would aid more from the set from which words of a lower frequency are producible via a convergence by manipulation of orthographic neighbourhood, and in terms of the fact that longer English words tend to have fewer neighbours than shorter words, more words but of a shorter length would be produced from the letter set from which lower frequency words are produced since manipulation aids production more from the less frequent set. The fact that the length effect is reversed in Experiment 1.2 provides further evidence of a possible interfering effect between languages, and the fact that this reversal effect resolves in Experiment 2 where different stimuli are used, such that a significant main effect is observed for letter set when the task is performed in English but that no significant main effect is observed when the task is performed in Afrikaans, provides evidence in favour of this conclusion. Again, this cannot be conclusively demonstrated however.

Overall, the general lack of significant main effects for physical manipulation (with the exception of the main effect on average word length in Experiment 2.1) illustrates that the model is fairly weakly supported by the data, as main effects for manipulation were predicted via a number of mechanisms. The model is fairly good in predicting cross-language differences, in that a seemingly opposite pattern of results to Experiment 1.1 was obtained for Experiment 1.2, and moreover, in the post-hoc analyses of the letter set for which the use of manipulation aided production, a slightly larger effect size was obtained in Experiment 1.2 compared to Experiment 1.1. Furthermore, the fact that certain findings such as the possible interaction between letter set and physical manipulation, in terms of the fact that manipulation aids more for production from the set from which less frequent words are made, were also predicted on the basis of the model.

5.3 Limitations and Suggestions for Future Research

One of the greatest limitations of the present research relates to the lack of an explicit, objective, and valid measure of language proficiency. This would have resulted in stronger conclusions regarding the between-language interference effects to be drawn, as well as a determination of the relative influence that language proficiency has in the present task. Such a test may have included a self-rating scale for bilingualism as well as a test of speeded reading of short texts, such as that used by Segalowitz and Frenkial-Fishman (2005). However, as these authors note, self-rating scales are inherently subjective and reading tasks involve too many sources of variability.

Another possibility may have been to measure lexical access according to an animacy judgement task, such as that used by Segalowitz and Frenkial-Fishman (2005), in which a noun appears on the screen and participants are required to classify it into either something living or non-living. The mechanism by which lexical access in bilinguals occurs is a contested topic however, as noted in Chapter 2, and therefore measuring efficiency of access is relatively difficult. If language proficiency is taken as a measure of efficiency of lexical access, and since proficiency in English is relatively easy to measure through a variety of language proficiency tests, although not performed in the present study as the aim of the present research was to investigate cross- as opposed to within-language effects, a future study in this regard may examine the performance of epistemic actions in a group of highly proficient speakers relative to a group of speakers of low proficiency. The hypothesis would therefore be that the performance of physical manipulation would aid more for the group of low proficiency.

A second limitation pertains to the fact that a comparison experiment involving a group of L1 Afrikaans and L2 English speakers, in order to investigate a possible cross-over of the effects observed in the present experiments, was not performed. Such a comparison is undoubtedly an area of further research, however, such an experiment could not be performed in the present study as the participants were to be sourced from the University of Cape Town, which has a large population of first language English speakers, and the time involved in gathering an adequately large sample of L1 Afrikaans speakers would have been prohibitive in this regard. In fact, it was significantly difficult to gather a sample of first language Afrikaans speakers to produce data for the norming task for Experiment 1.

A third limitation in the present research concerns the lack of a comparison of a group of experts at anagram solution with a group of non-experts, which would have proved fruitful considering that previous research (e.g., Maglio & Kirsh, 1996) has demonstrated that experts at a particular task take more epistemic actions, and that experts at Scrabble show superior performance on selected verbal and visuospatial tasks relative to novices (e.g., Halpern & Wai, 2007). In addition, research by Novick and Sherman (2003, 2007) has shown that the strategies employed by expert anagram solvers are different to the strategies employed by non-experts, with experts favouring solution based on structural characteristics of the anagram and non-experts favouring solution based on superficial characteristics of the anagram. However, the present study was not an examination of the relative influence of expertise at the task, as it was primarily a cross-linguistic replication of the Maglio *et al.* (1999) study. Of course an experiment which involves examining experts at Scrabble and/or anagram solution, as well as high versus low language proficiency, and the interaction between expertise and language proficiency, would be valuable in teasing out the relative contributions of task and linguistic expertise.

In terms of the fact that the present set of experiments were purely experimental in nature, a process measure of the processes underlying the mechanism by which the performance of epistemic actions in the task used in these experiments would allow a more finer testing and refinement of the model presented in Chapter 2. In this regard, a protocol analysis, which involves collecting verbal reports of cognitive processes from participants in order to elucidate the cognitive processes underlying performance in a task (Ericcson & Simon, 1993), would allow an investigation of the specific way in which participants use epistemic actions in the task, as opposed to examining simply whether or not performing epistemic actions aids in word production.

Considering the suggestion made earlier that physical manipulation in the task used in the present research may simply serve an error-checking function, a possible study examining the effect of epistemic actions on reducing the error-rate, in other words the number of false-positive words formed from a letter string (i.e., words which the participant believes to be producible from the letter string but which actually aren't), would be particularly insightful. Such an experiment could involve the solvability judgement task, a task in which letter strings are presented and the participant is required to decide whether each letter string could be unscrambled to form a word (Novick & Sherman, 2003). If we expect epistemic actions to reduce the probability of error of mental computation (Kirsh & Maglio, 1994), it can be expected that in an experiment such as this that discrimination between solvable and unsolvable letter strings would be better if physical manipulation of the stimulus is allowed.

5.4 Conclusion

The present set of experiments sought to undertake a cross-linguistic replication of the original experiment conducted by Maglio *et al.* (1999), in which it was discovered that physical manipulation in a task involving the production of words from a string of seven random letters aided in word production. The experiment of Maglio *et al.* (1999) was conducted on the basis of the epistemic action hypothesis, which states that performing physical actions can aid in cognition by allowing certain aspects of the task to be off-loaded to the environment, thus increasing the speed, accuracy, and robustness of performance. The results of Experiment 1 demonstrate that certain aspects of the original Maglio *et al.* (1999) experiment are replicable, although certain divergences were found. The results also indicate a cross-linguistic replication of the experiment, and demonstrate on the basis of a slightly larger effect size for manipulation in the post-hoc analysis that physical manipulation may aid for word production more when the task is performed in a second language.

However, in both the English and Afrikaans analysis, manipulation was found to influence word generation only for one of the two letter sets, indicating that the particular letter set used as a stimulus may interact with physical manipulation such that manipulation aids generation only for the set for which it is more difficult to produce words, where the frequency of the words produced from each letter set is taken as an implicit and semantic measure of the relative difficulty of producing words from each set. In this regard, a follow-up experiment (Experiment 2) was conducted which attempted a manipulation of the productiveness of the letter sets used as stimuli, in terms of the number of words producible from each letter set. This experiment discovered no significant main effect for physical manipulation for English or Afrikaans in terms of number of words produced, but a significant main effect for manipulation on the average length of the words produced was obtained, indicating further the reliability of the epistemic action effect, at least to some extent. The present set of experiments therefore provides evidence that the epistemic action effect is not as ubiquitous in aiding cognitive processing as was previously thought.

In terms of the fact that possible cross-language interference effects were predicted on the basis of the model presented in Chapter 2, and that these effects did possibly occur (although other explanations are also possible), the present set of experiments also provides some evidence towards the fact that epistemic actions may aid more when the task is performed in a second language, and that the relative influence and mechanism by which epistemic actions aid in performance in the task may possibly differ as a function of whether the task is performed in a first or second language. Additional research exercising far more control over linguistic variables is clearly required in order to unpack the relative influence of linguistic variables and physical action, and the interaction between the two, in a task such as that used in the present set of experiments.

References

Adams, F., & Aizawa, K. (2001). The bounds of cognition. *Philosophical Psychology, 14,* 43-64.

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review, 4,* 439-461.

Aydelott, J., & Bates, E. (2004). Effects of acoustic distortion and semantic context on lexical access. *Language and Cognitive Processes, 19,* 29-56.

Binder, J. R., McKiernan, K. A., Parsons, M. E., Westbury, C. F., Possing, E. T., Kaufman, J. N., & Buchanan. L. (2003). Neural correlates of lexical access during visual word recognition. *Journal of Cognitive Neuroscience, 15,* 372-393.

Carr, T. H. (1992). Automaticity and cognitive anatomy: Is word recognition "automatic"? *The American Journal of Psychology, 105,* 201-237.

Cenoz, J. (2001). The effect of linguistic distance, L2 status and age on cross-linguistic influence in third language acquisition. In J. Cenoz, B. Hufeisen, & U. Jessner (Eds.), *Cross-linguistic influence in third language acquisition: Psycholinguistic perspectives* (pp. 8-20). Clevedon: Multilingual Matters.

Chemero, A. (1998). A stroll through the worlds of animats and persons: A review of Andy Clark's *Being there. Psyche, 4.* Retrieved March 22 2006 from http://psyche.cs.monash.edu.au/v4/psyche-4-14-chemero.html

Clark, A. (1997). *Being there: Putting brain, body, and world together again.* Cambridge, MA & London, UK: MIT Press.

Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences, 3,* 345-351.

Clark, A. (2005a). Intrinsic content, active memory and the extended mind. *Analysis, 65,* 1-11.

Clark, A. (2005b). Word, niche and super-niche: How language makes minds matter more. *Theoria, 54,* 255-268.

Clark, A., & Chalmers, D. (1998) The extended mind. *Analysis, 58,* 7-19.

Cornelissen, P. L., Hansen, P. C., Gilchrist, I., Cormack, F., Essex, J., & Frankish, C. (1998). Coherent motion detection and letter position encoding. *Vision Research, 38,* 2181-2191.

Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language, 50,* 491-511.

Costa, A., Miozza, M., & Caramazza, A. (1999). Lexical selection in bilinguals: Do words in the bilingual's two lexicons compete for selection? *Journal of Memory and Language, 41,* 365-397.

Dijkstra, T., Timmermans, M., & Schriefers, H. (2000). On being blinded by your other language: Effects of task demands on interlingual homograph recognition. *Journal of Memory and Language, 42,* 445-464.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data* (rev. ed.). Cambridge, MA & London, UK: MIT Press.

French, R. M., & Ohnesorg, C. (1995). Using non-cognate interlexical homographs to study bilingual memory organization. In *Proceedings of the seventeenth annual conference of the Cognitive Science Society* (pp. 31-36). Hillsdale, NJ: Lawrence-Erlbaum Associates.

Furby, L. (1977). Anagram solving strategies in children. *The Journal of General Psychology, 96,* 267-279.

Gollan, T. H., & Kroll, J. F. (2001). Bilingual lexical access. In B. Rapp (Ed.), *The handbook of cognitive neuropsychology: What deficits reveal about the human mind* (pp. 321-346).

Grainger, J., & Beauvillain, C. (1987). Language blocking and lexical access in bilinguals. *The Quarterly Journal of Experimental Psychology, 39A,* 295-319.

Gavurin, E. (1967). Anagram solving and spatial aptitude. *Journal of Psychology, 85,* 65-68.

Gavurin, E., & Zangrillo, R. L. (1975). Effect of bigram cues on the solution of monosyllabic and bisyllabic solution-word anagrams. *The Journal of General Psychology, 92,* 225-229.

Gernsbacher, M. A. (1984). Resolving 20 years of inconsistent interactions between lexical familiarity and orthography, concreteness, and polysemy. *Journal of Experimental Psychology: General, 113,* 256-281.

Gilhooly, K. J., & Johnson, C. E. (1978). Effects of solution word attributes on anagram difficulty: A regression analysis. *Quarterly Journal of Experimental Psychology, 30,* 57-70.

Halpern, D. F., & Wai, J. (2007). The world of competitive Scrabble: Novice and expert differences in visuospatial and verbal abilities. *Journal of Experimental Psychology: Applied, 13,* 79-94.

Hutchins, E. (2000). Distributed cognition. Retrieved April 12 2006 from http://eclectic.ss.uci.edu/~drwhite/Anthro179a/DistributedCognition.pdf

Hutchins, E., & Klausen, T. (1996). Distributed cognition in an airline cockpit. In D. Middleton & Y. Engestrom (Eds.), *Communication and cognition at work* (pp. 15-34). Cambridge, UK: Cambridge University Press.

Kelly, M. H., & Martin, S. (1994). Domain-general abilities applied to domain-specific tasks: Sensitivity to probabilities in perception, cognition, and language. In L. Gleitman & B. Landau (Eds.), *The acquisition of the lexicon* (pp. 105-140). Cambridge, MA & London, UK: MIT Press.

Kirsh, D. (1995a). Complementary strategies: Why we use our hands when we think. In *Proceedings of the seventeenth annual conference of the Cognitive Science Society* (pp. 212-217). Hillsdale, NJ: Lawrence-Erlbaum Associates.

Kirsh, D. (1995b). The intelligent use of space. *Artificial Intelligence, 73,* 31-68.

Kirsh, D. (1996). Adapting the environment instead of oneself. *Adaptive Behaviour, 4,* 415-452.

Kirsh, D. (2006). Distributed cognition: A methodological note. *Pragmatics and Cognition, 14,* 249-262.

Kirsh, D., & Maglio, P. (1992a). Some epistemic benefits of action: Tetris, a case study. In *Proceedings of the fourteenth annual conference of the Cognitive Science Society* (pp. 224-229). Hillsdale, NJ: Lawrence-Erlbaum Associates.

Kirsh, D., & Maglio, P. (1992b, March). Perceptive actions in Tetris. In R. Simmons (Chair), *AAAI spring symposium on control of selective perception,* Stanford University.

Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science, 18,* 513-549.

Kroll, J. F., Michael, E., Tokowicz, N., & Dufour, R. (2002). The development of lexical fluency in a second language. *Second Language Research, 18,* 137-171.

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.

Lezak, M., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment* (4th ed.). Oxford: Oxford University Press.

Maglio, P., & Kirsh, D. (1996). Epistemic action increases with skill. In *Proceedings of the eighteenth annual conference of the Cognitive Science Society* (pp. 391-396). Mahwah, NJ: Lawrence-Erlbaum Associates.

Maglio, P., & Wenger, M. J. (2000). Two views are better than one: Epistemic actions may prime. In *Proceedings of the twenty-second annual conference of the Cognitive Science Society* (pp. 818-823). Mahwah, NJ: Lawrence-Erlbaum Associates.

Maglio, P., & Wenger, M. J. (2002). On the potential of epistemic actions for self-cuing: Multiple orientations can prime 2D shape recognition and use. In *Proceedings of the twenty-fourth annual conference of the Cognitive Science Society* (pp. 608-613). Mahwah, NJ: Lawrence-Erlbaum Associates.

Maglio, P., Wenger, M. J., & Copeland, A. M. (2003). The benefits of action outweigh the costs. In *Proceedings of the twenty-fifth annual conference of the Cognitive Science Society* (pp. 752-757). Mahwah, NJ: Lawrence-Erlbaum Associates.

Maglio, P., Matlock, T., Raphaely, D., Chernicky, B., & Kirsh, D. (1999). Interactive skill in Scrabble. In *Proceedings of the twenty-first annual conference of the Cognitive Science Society* (pp. 326-330). Mahwah, NJ: Lawrence-Erlbaum Associates.

Marian, V., Spivey, M., & Hirsch, J. (2002). Shared and separate systems in bilingual language processing: Converging evidence from eyetracking and brain imaging. *Brain and Language, 86,* 70-82.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88,* 375-407.

McGinnies, E., Comer, P. B., & Lacey, O. L. (1952). Visual-recognition thresholds as a function of word length and word frequency. *Journal of Experimental Psychology, 44,* 65-69.

Menary, R. (2006). Attacking the bounds of cognition. *Philosophical Psychology, 19,* 329-344.

Mendelsohn, G. A. (1976). An hypothesis approach to the solution of anagrams. *Memory & Cognition, 4,* 637-642.

Mendelsohn, G. A., & Covington, M. V. (1972). Internal processes and perceptual factors in verbal problem solving: A study of sex and individual differences in cognition. *Journal of Personality, 40,* 451-71.

Newell, A., & Rosenbloom, P. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1-55). Hillsdale, NJ: Lawrence-Erlbaum Associates.

Novick, L. R., & Cote, N. (1992). The nature of expertise in anagram solution. In *Proceedings of the fourteenth annual conference of the Cognitive Science Society* (pp. 450-455). Mahwah, NJ: Lawrence-Erlbaum Associates.

Novick, L. R., & Sherman, S. J. (2003). On the nature of insight solutions: Evidence from skill differences in anagram solution. *The Quarterly Journal of Experimental Psychology, 56A,* 351-382.

Novick, L. R., & Sherman, S. J. (2007). The effects of superficial and structural information on online problem solving for good versus poor anagram solvers. *The Quarterly Journal of Experimental Psychology, 1,* 1-23.

Penn, C., Venter, A., & Ogilvy, D. (2001). Aphasia in Afrikaans: A preliminary analysis. *Journal of Neurolinguistics, 14,* 111-132.

Pinckney, G. A., & Kwiatkowski, B. M. (1977). Transitional probability effects on anagram solving in a group setting. *The Journal of Psychology, 95,* 3-6.

Rogers, Y. (2006). Distributed cognition and communication. In K. Brown (Ed.), *Encyclopedia of language and linguistics* (2nd ed.) (pp. 181-202). Oxford, UK: Elsevier.

Segalowitz, N., & Frenkial-Fishman, S. (2005). Attention control and ability level in a complex cognitive skill: Attention shifting and second-language proficiency. *Memory & Cognition, 33,* 644-653.

Sieroff, E., & Posner, M. I. (1988). Cueing spatial attention during processing of words and letter strings in normals. *Cognitive Neuropsychology, 5,* 451-472.

Tremblay, M. C. (2006). Cross-linguistic influence in third language acquisition: The role of L2 proficiency and L2 exposure. *Cahiers Linguistiques d'Ottawa/Ottawa Papers in Linguistics, 34,* 109-119.

van Heuven, W. J. B., Dijkstra, T., & Grainger, J. (1998). Orthographic neighbourhood effects in bilingual word recognition. *Journal of Memory and Language, 39,* 458-483.

Van Rooy, B. (2002). *Transkripsiehandleiding van die korpus gesproke Afrikaans* [Transcription manual of the corpus spoken Afrikaans]. Potchefstroom: Potchefstroom University.

Vitevitch, M .S., & Rodriguez, E. (2005). Neighbourhood density effects in spoken word recognition in Spanish. *Journal of Multilingual Communication Disorders, 3,* 64-73.

Wallace, I. G. (1977). The role of overt letter rearrangement in anagram solving in subjects of high and low spatial ability and anagrams of two levels of difficulty. *The Journal of General Psychology, 96,* 117-124.

Wallace, I. G. (1979). Letter order randomization in anagram solving. *The Journal of General Psychology, 101,* 65-73.

Wilson, M. D. (1988). The MRC Psycholinguistic Database: Machine Readable Dictionary, Version 2. *Behavioral Research Methods, Instruments and Computers, 20,* 6-11.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin and Review, 9,* 625-636.

Witte, K. L., & Freund, J. S. (2001). Single-letter retrieval cues for anagram solution. *The Journal of General Psychology, 128,* 315-328.

Ziemke, T. (2001, July). *Disentangling notions of embodiment.* Paper presented to the Workshop on Developmental Embodied Cognition, Edinburgh, United Kingdom.

Appendix A

Distractor Tasks

This appendix presents a description of the distractor tasks used in both experiments, a version of the Babcock Story Recall task adapted for the South African context, and the Rey-Oesterith Complex Figure.

A.1 Babcock Story Recall Task

This is a paragraph recall test which comprises a 21-unit story (presented below). The story used in the present set of experiments was adapted for the South African context from the original story. The test begins with the instruction: "I am going to read a short story to you now. Listen carefully because when I finish I'm going to ask you to tell me as much of the story as you can remember" (Lezak *et al.,* 2004). After the story was read, participants were immediately required to write down as much of the story as they remembered.

> On December the 6th, / last week, / a river / overflowed / in a small town / ten kilometres / from Knysna. / Water covered the streets / and entered the houses. / Thirteen people / were drowned / and 600 people / caught colds / because of the dampness / and cold weather. / In trying to save / a boy / who was caught / under a bridge, / a man / cut his hands.

A.2 Rey-Oesterith Complex Figure Task (Copy Administration)

According to Lezak *et al.* (2004), this task involves both perceptual organisation and visual memory (Lezak *et al.*, 2004). In this task, the participants were presented with the Rey-Oesterith Complex Figure, which cannot be presented here as it is copyrighted (see Lezak *et al.*, 2004, p. 537 for what the figure looks like), which was set out such that its length runs along the page. The task involved copying, on a blank piece of white un-lined paper, the figure presented.

Appendix B

Letter String Productiveness Calculator

This appendix presents the modified version of the algorithm presented in Appendix C of Jordan and Monteiro (2003) that was used to compute the productiveness of the random letter strings from which the stimuli selection for Experiment 2 took place.

```
#include <stdio.h>
#include <string.h>

void stripnl(char* s)
{
        for (int k = 0; k < (int)strlen(s); k++)
        {
                if (s[k] == '\n')
                {s[k] = 0; return;};
        }
}

void do_permutations(int nLetters, char** pArray, int nPerm_lines)
{
        int nCR;
        int nCurrRow = 1;


        for (int m=2; m<(nLetters+1); m++)
        {
                nCR = nCurrRow;

                for(int i = 0; i < nCR; i++)
                {
```

```
                    strcpy(pArray[nCurrRow], pArray[i]);
                    for (int nSwap = 1; nSwap < m; nSwap++)
                    {
                        char chTmp1 = pArray[nCurrRow][(m-nSwap)];
                        char chTmp2 = pArray[nCurrRow][((m-nSwap)-1)];

                        pArray[nCurrRow][(m-nSwap)] = chTmp2;
                        pArray[nCurrRow][((m-nSwap)-1)] = chTmp1;
                        nCurrRow +=1;

                        if(nCurrRow < nPerm_lines)
                        {
                            strcpy(pArray[nCurrRow],   pArray[(nCurrRow-
1)]);
                        }

                    }
                }
            }
}

int nbang(int input)
{
    int i = input;
    int result = 1;

    for (int k = input; k > 0; k--)
    {
        result *= k;
    }

    return result;
}
```

```
void calc_generativity(int max_wordsize, char** anagrams, int anagrams_size)
{

	char buff[80];
	char buff2[80];
	FILE* dict;
	FILE* kill = fopen("results_words.txt", "wt");
	fclose(kill);

	for (int a = 0; a < anagrams_size; a++)
	{
		for (int r = 2; r < max_wordsize; r++)
		{
			printf("Progress: %d-%d (total anagrams to test: %d)\r", a+1, r,
anagrams_size);
			dict = fopen("dictionary.txt", "rt");
			//walk the dictionary looking for this word
			while(1)
			{
				fgets(buff, 80, dict);
				if(feof(dict))break;
				if(buff[0] == '\n') break;
				stripnl(buff);
				if (strncmp(anagrams[a], buff, strlen(buff)) == 0)
				{
					int add_word = 1;
					FILE* test = fopen("results_words.txt", "rt");
					if (test)
					{
						while(1)
						{
							fgets(buff2, 80, test);
							if(feof(test))break;
							if(buff2[0] == '\n') break;
```

```
                                                stripnl(buff2);
                                                if      (strncmp(buff2,        buff,
strlen(buff)) == 0)
                                                {
                                                        add_word = 0;
                                                        break;
                                                }
                                        }
                                        fclose(test);
                                }

                                if (add_word)
                                {
                                        FILE* add = fopen("results_words.txt",
"at");

                                        fprintf(add, "%s\n", buff);
                                        fclose(add);
                                }

                        }

                }

                fclose(dict);
        }
}


int histo[25];
for (int k = 0; k < 25; k++)
        histo[k] = 0;

int count = 0;
FILE* add = fopen("results_words.txt", "rt");
```

```
        while(1)
        {
                fgets(buff2, 80, add);
                if(feof(add))break;
                if(buff2[0] == '\n') break;
                histo[strlen(buff2)-1]++;
                count++;
        }
        fclose(add);
        add = fopen("results_words.txt", "at");
        fprintf(add, "---Generates %d words\n", count);
        fprintf(add, "---Histo:\n");
        for (k = 2; k < max_wordsize+1; k++)
        {
                fprintf(add, "---%2d letters: %d words\n", k, histo[k]);
        }
        fclose(add);
        printf("\nAll done\n");
}

int main()
{
        FILE* in = fopen("letterset.txt", "rt");
        if (!in)
        {
                printf("ERROR: Could not open letterset.txt\n");
        }
        FILE* dict = fopen("dictionary.txt", "rt");
        if (!dict)
        {
                printf("ERROR: Could not open dictionary.txt\n");
        }
        fclose(dict);
```

```
        char letterset[256];
        fgets(letterset, 256, in);
        fclose(in);
        for (int k = 0; k < 256; k++)
        {
                if (letterset[k] == '\n') letterset[k] = '\0';
        }

        int results = nbang(strlen(letterset));

        char** anagrams = NULL;
        anagrams = new char*[results];

        for (k = 0; k < results; k++)
        {
                anagrams[k] = new char[80];
                anagrams[k][0] = '\n';
        }

        strcpy(anagrams[0], letterset);
        do_permutations(strlen(letterset), anagrams, results);

        calc_generativity(strlen(letterset), anagrams, results);

        for (k = 0; k < results; k++)
        {
                delete[] anagrams[k];
        }
        delete[] anagrams;


        return 0;
}
```

Appendix C

Computed Productiveness of Letter Set Stimuli

This appendix presents the letter strings, and the computed productiveness thereof, that were produced from the computer programme based on a modified version of the computational algorithm presented in Jordan and Monteiro (2003), and from which the selection of the stimuli for Experiment 2 were made.

ENGLISH		AFRIKAANS	
Letter String	Computed Productiveness	Letter String	Computed Productiveness
NRPGOQX	12	URJNNES	7
ATNNDER	59	ETGPNDU	15
HAONNBE	31	HTWRAAE	19
IAEITMG	35	HAEGNLO	24
EARNLEE	26	HIGNDSY	17
LTBGNTE	17	TDTAAII	4
LROEVHR	27	NITTWKE	20
GEAEHUT	32	JDTDTDO	1
KXNEMEN	10	GYVSARH	22
GBIOVIA	11	OAJERWE	7
LPBESCE	28	RKEEMEK	7
TLLPEGD	13	UPYAAEW	3
CAOBISL	52	FEVTDHS	6
AASDUKQ	16	VMRFHWI	1
NEZYRDN	15	EVHATMS	20
SONOAEO	19	LGTTEAO	19
EASEIQE	5	JUEWNDI	12
OEOCSDI	38	ENRAIVV	19
OEWXEEU	8	PTEAVAT	8
ITNGLNR	23	EEVAISG	21
UNERMYK	24	DIIEDBW	7
AGIEHQL	20	NGHEREK	22
GFOADIT	44	AAATDOO	1
IEOGBGE	15	NNSDDUG	3
NETNKEE	10	HVKASNT	21
IESFPNB	36	TOIEEYH	10
LYTTAAD	10	ODLAHUO	6

TRALSEG	110	RWIOPAO	7
OTLCCIR	26	TKSYNPR	13
GTUOMJC	22	HWEIERI	11
RAAORLP	17	JTNGDAS	27
SDBNEAA	48	DLIHDAD	4
IXEEMNO	23	RESJRIS	7
RRRNAUU	4	IEGPAEP	10
AIEUTAZ	9	IEDREAE	16
TPLGEEJ	16	IGAIEBJ	11
KSDECDN	13	ETRNPID	26
DAEEAAO	4	VREGTTI	18
IGMNAIL	28	AEEIBTD	24
BETMIGO	42	PMEIIUS	12
EMODEIL	49	WOUATIS	20
TMOSHTI	49	LIWIOAE	9
AREAFYE	28	ANVNIHA	11
ANDTOYS	61	UKESDRG	19
OIYTHNN	30	EEFSENE	8
HEEIETT	15	IRIAGRK	8
SVYYEAD	20	OKEIEML	24
XTZASVG	15	BWEIEDG	21
RTSDLEE	47	EPFGSOO	13
ESRIAAY	42	BEENOAL	17
EEPRIWO	41	VOITGDH	4
IPOLRQE	34	EEEITSE	11
ERRABPA	30	SOEVWUL	12
EANAGID	30	EEEAEGE	4
SNOHQEA	40	RAAYHGP	17
HEGXGIE	10	ISAEMWD	20
FPMEDER	26	EPMVRED	14
EOFSEAE	15	LDDEITH	11
GIDTRBK	23	EYAEEEU	2
JNAMONS	20	OUEOENT	17
ISMEAVO	33	ATUEETN	17
DPEAJAL	24	NERIIVO	11
MOENREO	26	FNPNOHL	3
PANUDBS	59	TSENAHY	23
SLAUDKR	27	DRGYIEA	21
YYQCFUA	4	WDSLAHT	13
RIYLOHE	37	EOEAOPI	7

SILESSW	15	AOJVLNI	9
OIALRIS	36	AFRRWST	11
RNRERFE	13	EGSILNA	47
TDBOLII	33	UIJISGI	5
UOTIVNI	19	HGAEEEJ	7
MOHIHMS	22	DOTHTEM	14
CTLULYO	18	DTALSNG	36
SROOEAV	41	EWBPESA	14
DEENTIR	65	DAISROE	28
GEURNKE	28	ETYMSTT	8
LOMRGLS	14	EREIRAE	9
EADHIGB	42	RAEVEDG	24
INETIIE	12	ATGTEIS	21
OGEDYIN	47	LDEAAYS	17
TCITIRA	22	ISIFLDH	3
GPUROET	66	ATTESSN	16
JHNRHIB	6	ASEKTUI	32
ILVEJST	46	GTNANBE	19
RELINNY	23	AEFNDWI	21
PIIEAOH	20	SNETDKV	17
IRGAAAL	15	KPRIWVD	1
RWAJILU	14	YRNIRAE	13
EYMEOEZ	6		
LEIYPAA	29		
BISKFAO	30		
YFPBENY	9		
DEEOOHC	24		
SUOHEGN	66		
NEZOYOT	26		
UULNCTG	13		
EISKRII	13		
ECVNYOP	34		
URKAFGN	28		